

University of Bahrain

College of Science



Department of Physics

Measuring the External Natural Background Radiation in Areas Affected by NORM in the Kingdom of Bahrain

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Master of Environment and Sustainable Development

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ABSTRACT

A study of the natural external background radiation in areas affected by Naturally Occurring Radioactive Materials (NORM) has been performed in the Kingdom of Bahrain. It is known that the extraction of oil and gas enhances NORM leading to higher radiation levels. Awali and Riffa Views residential areas are located in the center of the Kingdom of Bahrain. These areas characterize by presence of extensive oil and gas operations and transportations. Awali and Riffa Views have therefore been selected as experimental areas. Two more areas namely; Isa Town and AL-Budaiya Village have been also studied in this work. Such areas, since no industrial activities are present, are expected to have natural background radiation that is not affected by such activities. A hand-held Colibri Very Low Dose (VLD) radiation survey meter with built-in GPS has been used to measure and map the natural external background radiation for the four studied areas. The meter's GPS has been enabled and radiation measurements have been acquired manually at a distance of every 300 meters intervals and at height of one meter above the ground. Mapping of the radiation profiles of the studied areas has been performed using Google Map Macro online application. The lowest radiation dose rate acquired has been $0.02 \mu\text{Sv/h}$ acquired in Isa Town while the highest has been $0.37 \mu\text{Sv/h}$ occurred in Awali. It has also been found that the mean annual equivalent doses of Isa Town, Al-Budaiya, Awali and Riffa Views; $0.70 \pm 0.26 \text{ mSv/y}$, $0.79 \pm 0.35 \text{ mSv/y}$, $2.07 \pm 0.66 \text{ mSv/y}$ and $1.37 \pm 0.44 \text{ mSv/y}$ respectively. The radiation exposures in the experimental areas exceeded the maximum permissible limit 1 mSv/y as recommended by ICRP-60. Particularly in south and southwestern Awali in which the mean annual equivalent dose has reached up to $2.80 \pm 0.79 \text{ mSv/y}$. High radiation levels in Awali and Riffa Views could be regarded to the presence of extensive oil and gas operation and installations in these areas.

DEDICATION

I would like to dedicate this work to my lovely wife and my family for supporting me spiritually throughout my life.

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ABBREVIATIONS

ASR: Age Standardized cancer incidence Rate

Bq: Becquerel

CanNORM: Canada Naturally Occurring Radioactive Materials

CsI: Cesium Iodide

DNA: Deoxyribonucleic acid

GCC: Gulf Cooperation Council

GPS: Geographical Positioning System

Gy: Gray

ICRP-60: International Council for Radiation Protection-60

LNT: Linear No Threshold

MDA: Minimum Detectable Activity

mSv: Milli-Sievert

NORM: Naturally Occurring Radioactive Materials

REM: Roentgen Equivalent in Man

SD: Standard Deviation

Sv: Sievert

UKIRR: United Kingdom Ionizing Radiation Regulation

VLD: Very Low Dose

CHAPTER ONE

INTRODUCTION TO THE STUDY

- 1.1 Introduction
- 1.2 Types of Ionizing Radiation
- 1.3 External and Internal Exposures to Radiation
- 1.4 Units of Ionizing Radiation
- 1.5 Radiation Dosimetry
- 1.6 Health Risks from the Exposure to Ionizing Radiation
- 1.7 Sources of Natural Background Ionizing Radiation
 - 1.7.1 Extraterrestrial Radiation
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 - 1.7.3 Anthropogenic Sources
 - 1.7.3.1 Oil and Gas Exploration
- 1.8 Research Problem
 - 1.8.1 Factors Affecting the Exposure to Ionizing Radiation
- 1.9 Research Objectives
- 1.10 Research Significance
- 1.11 Definitions of Terms

CHAPTER ONE: INTRODUCTION TO THE STUDY

1.1 Introduction

Life on earth has evolved with a significant amount of ionizing radiation due to the decay of natural long-lived radioisotopes (WNA, 2012). Natural background ionizing radiation is naturally and inevitable characteristic in our environment and has always been present around us in many natural forms (CNSC, 2013). While medical exposures contribute to about 12% of the annual radiation dose to the world population, the natural background ionizing radiation contributes to the most of the remaining 88% (UNSCEAR, 2008).

1.2 Types of Ionizing Radiation

The most common types of ionizing radiation are alpha and beta particles and gamma rays. The ionizing radiation is the radiation that has the ability to produce ions as it passes through a matter (IAEA, 2003). These ions able to disrupt the function of some important biological molecules like the Deoxyribonucleic Acid (DNA) (CNSC, 2013).

Alpha particles are large positively charged molecules (IAEA, 2003). Some of the naturally heavy radionuclides such as Uranium and Radium emit alpha particles as they decay (CNSC, 2013). Due their relative large size and charge, alpha particles have a little penetration power (UNSCEAR, 2009). They can travel a few centimeters in air and can be stopped by a sheet of paper (IAEA, 2003). Alpha particles do not cause harm to humans unless they are ingested or inhaled (UNSCEAR, 2009).

Beta particles are similar to electrons; they are negatively charged and have smaller mass compared to the alpha particles. Beta particles are ejected from many types of radionuclides. Similar to alpha, beta particles have a limited penetrability due to their size and charge (IAEA, 2003). However, they can travel up to ten feet in air before they lose their energy. Beta particles are able to penetrate up to two centimeters of water (UNSCEAR, 2009). The main concerns from the beta particles are those effects to the human eyes and skin or to the internal organs if they ingested (IAEA, 2003).

Gamma rays are electromagnetic photons emitted when radioactive radionuclides undergo alpha or beta decay. They have neither mass nor electrical charge. Therefore, the chance of interaction with other matters is less likely. Accordingly, gamma rays possess a greater penetration power in which they can travel longer distances in matter and can be stopped by few centimeters of lead (Museum of the Earth, 2011; CNSC, 2013). The result of the exposure to the gamma rays is irradiation of the whole human bodies rather than small body areas (IAEA, 2003).

1.3 External and Internal Exposures to Radiation

There are two types of exposure to the ionizing radiation; external and internal exposures (MSU, 2011; HPS, 2012). On one hand, the external hazard arises when radiation from a source external to the body penetrates the body and causes a dose of ionizing radiation. Gamma radiation is responsible for the most natural external background ionizing radiation (MSU, 2011). On the other hand, radioactive particles may be internally deposited in the human bodies (UNSCEAR, 2009; MSU, 2011).

The internal deposition occurs when the radioactive material is airborne inhaled and deposited in the lungs; ingested via contaminated food, drink or other consumable items; or spilled onto the skin. Radon, which is the decay product of the Uranium, forms the largest source of internal background radiation exposure to human kinds (UNSCEAR, 2008; Hendry et al., 2009).

1.4 Units of Ionizing Radiation Measurements

The Becquerel (Bq) is the international unit of the radioactivity. It defines as the amount of ionizing radiation emitted per a radioactive decay or it is one disintegration per second (UNSCEAR, 2009). The absorbed dose from the exposure to ionizing radiation by a person is measured in terms of Gray (Gy). Gray is defined as one joule of energy deposited per kilogram of a mass (IAEA, 2003). Different types of body tissues have different radio-sensitivities to the same radiation exposure. The term used to describe the effect of the ionizing radiation on human tissues is the equivalent dose (UNSCEAR, 2009). Sievert (Sv) is the international unit for the equivalent dose. It is used to represent the stochastic effects that result from the exposure to low levels of ionizing radiation (Morgan et al., 2009). In the United States, the unit rem, which is the acronym for the Roentgen Equivalent in Man, is used widely to describe radiation related biological effects instead of Sievert (Table 1).

Table (1)

SI and US conversion equivalence (ORISE, 2015)

SI units	US units
1Becquerel (Bq)	3.7×10^{-10} Curie (Ci)
1 Gray (Gy)	100 Rad
1 Sievert (Sv)	100 rem

1.5 Radiation Dosimetry

The International Council for Radiation Protection-60 (ICRP-60) has categorized those who are exposed to the ionizing radiation. Occupational radiation workers are those who are exposed to the ionizing radiation routinely. The occupational exposure involves all radiation related to the practice except the exposure to the natural background radiation. This category is required to carry radiation-monitoring devices during their practice. The maximum permissible occupational radiation dose from external sources is 20 mSv/y. On the other hand, the maximum allowable external radiation dose for the general public or non-nuclear industrial occupations is 1 mSv/y (Table 2) (ICRP-60).

Table (2)
Recommended external public, patients and occupational exposures
(ICRP-60, 1991)

Application	Effective dose
Occupational exposure	20 mSv/y
Patient exposure	5 mSv/y
Public exposure non-nuclear industrial occupations	1 mSv/y

1.6 Health Risks Arise from the Exposure Ionizing Radiation

It is well known that the exposure to the ionizing radiation involves some risks to human health (UNSCEAR, 2008; Pearce et al., 2012). There are two main biological radiation effects; the stochastic and non-stochastic effects. The stochastic effects are those effects that occur when someone is exposed to low levels of ionizing radiation. The probability of the stochastic effects

increases as the exposure to the ionizing radiation increases. Stochastic effects occur due to mutations in the cell DNA that in turn evolve to produce either a cancer in the exposed person or a hereditary effect in the future generation of the exposed person. Usually, it takes many years between the time of the exposure to the ionizing radiation and the onset of the effect. Non-stochastic effects are those effects that occur when certain threshold of exposure to the ionizing radiation is reached. Non-stochastic effects usually result in a systemic cell death due to exposure to high levels of ionizing radiation (UNSCEAR, 2000).

Radium, which has a half-life of 1,602 years, becomes the radioactive legacy factor concerning our environment stewardship of this plant. Radium-226 produces an external radiation field of alpha and gamma radiation (Wilson, 1994).

1.7 Sources of Natural Background Ionizing Radiation

The natural background ionizing radiation originates from two main sources: natural radioactive materials and anthropogenic sources (HPS, 2012). The natural radioactive materials include both extraterrestrial rays and terrestrial radionuclides (Table, 3) (UNSCEAR, 2008). The anthropogenic sources involve nuclear plants, nuclear testing and nuclear accidents (Hendry et al., 2009). The anthropogenic sources also include certain industrial activities that are not related to the use of radioactive nuclides but their products, by-products and wastes increase or enhance the overall natural background radiation, for example, oil and gas extraction (UNSCEAR, 2008).

Table (3)**Public exposure to natural radiation (UNSCEAR, 2000)**

Source of exposure		Annual effective dose (mSv/y)	
		Average	Typical range
Cosmic radiation	Directly ionizing radiation component	0.28	-
	Neutron component	0.10	-
	Cosmogenic radionuclide	0.01	-
	Total cosmic and cosmogenic	0.39	0.3-1.0
External terrestrial radiation	Outdoor	0.07	-
	Indoor	0.41	-
	Total indoor and outdoor exposure	0.48	0.3-1.0
Inhalation	Uranium and thorium series	0.006	-
	Radon (222-Rn)	1.15	-
	Thoron (222-Rn)	0.1	-
	Total inhalation exposure	1.26	0.2-10
Ingestion	Potassium-40 (40-K)	0.17	-
	Uranium and thorium series	0.12	-
	Total ingestion exposure	0.29	0.2-1.0
Total		2.4	1.0-13

1.7.1 Extraterrestrial Radiation

The extraterrestrial radiation consists of energetic particles or photons from beyond the solar system that strike the Earth's atmosphere (UNSCEAR, 2008; Hendry et al., 2009). As it passes near to the Earth's atmosphere, the extraterrestrial radiation produces either radionuclides in the air or secondary ionizing radiation (HPS, 2012). Some of the secondary ionizing radiations are able to penetrate the Earth's atmosphere causing natural exposure to radiation (CNSC, 2013).

1.7.2 Terrestrial Radiation

The ionizing radiation that originates from the Earth's crust is called terrestrial radiation (HPS, 2012). The terrestrial radionuclides are headed by Uranium-235, Uranium-238, Thorium-232 and their decay products Radium-226 and Radium-228. Carbon-14 and Potassium-40 are also terrestrial radionuclides that contribute significantly to the average exposure to the natural internal background radiation (Smith, 1992). In the process of natural decay, these primordial radionuclides release; alpha, beta and gamma rays (HPS, 2012; CNSC, 2013).

1.7.3 Anthropogenic Sources

Nuclear accidents and nuclear testing release radioactive materials called fallout into the air. As the fallout settled on the ground, it incorporates into the environment resulting in significant elevation of the natural background radiation (CNSC, 2013). Yet, there are many industrial activities not related to the use of nuclear materials but their products, by-products or wastes may result in concentration and enhancement of the Naturally Occurring Radioactive Materials (NORM) (UNSCEAR, 2009). It occurs when radionuclides from underground formation brought to the Earth's surface. Uranium mining and milling, metal mining and smelting, oil and gas exploration are examples of technologies that contribute to NORM (Table 4) (UNSCEAR, 2008). This type of NORM is also referred to Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) (TENORM, 2014). Uncontrolled industrial activities accompanied with NORM could significantly increase human and environment exposure to the ionizing radiation (ICRP, 1977).

Table (4)**Industrial release of NORM in the United Kingdom (UNSCEAR, 2000)**

Industry	Discharge route	Pathway	Dose ($\mu\text{Sv/y}$)	
			Critical group	General public
Coal-fired power station	Atmospheric release via stack	All	1.5	-
	Building materials made from ash	Radon inhalation External	600 900	-
Oil and gas extraction	Authorized discharge to sea, and scales	Ingestion of seafood and external exposure due to fishing gear	>30	-
Gas-fired power station	Atmospheric release via stack	All	0.75	0.032
Steel production	Atmospheric release via stack	All	<100	-
	Building materials made from slag	Radon inhalation External	550 800	-
Zircon sands	Atmospheric release via stack	Inhalation	<1	<1

1.7.3.1 Oil and Gas Exploration

The oil and natural gas explorations and processing usually result in elevated levels of NORM (Vandenhove, 2000). The main concern of oil and gas NORM is Radium-226 and Radium-228. While Uranium and Thorium are quite immobile radionuclides, Radium tends to be soluble and easily mobilized in fluid media. That is why the Radium compounds are the most important radionuclide in Uranium-238 radioactive decay chain from radiobiological viewpoint. Radium radionuclides are usually associated with

carbonate formations for instance, clay-rich formations that contain shale, granites and some sandstones. The oil and gas normally found in these formations (Smith, 1992; Wilson, 1994). During oil and gas processing and transportation, Radium dissolved and transported to the surface of the Earth in the produced water waste stream (USGS, 1999). The produced water is naturally trapped water in oil and gas reservoirs and usually considered as a byproduct of oil and gas operations. The produced water itself contains low Radium concentration but volumes are large. Eventually, the produced water is discharged to the sea after treatment. (EPA, 2015). However, dissolved Radium either remains in the solution in the produced water or co-precipitates to form scale or sludge, depending on temperature and pressure conditions (Smith, 1992; USGS, 1999).

The scale composes mainly of insoluble Sulfate, Barium, Calcium, and Strontium compounds (EPA, 2015). Typically, the highest concentrations of Radium are found in Sulfate scale deposits (Table 5). Scale compounds usually associated with all equipment that come in contact with water for example, piping, filters, wellheads piping, disposal and injection wells. Yet, the radioactive sludge concentrates Radium much lower than the scale (Table 5) (Smith, 1992; TENORM, 2014). Usually, the sludge is found inside the piping, separators, heaters and storage tanks used to handle the produced water (OPG, 2008; UNSCEAR, 2009). The sludge generally consists of oily and loose material of silica compounds, but may also contain large amounts of Barium (EPA, 2015).

Table (5)
NORM in oil and gas production (Zaidan, 2010)

Type	Radionuclides	Characteristics	Occurrence
Ra scales	Ra-226, Ra-228, Ra-224 and their progeny.	Hard deposits of Ca, Sr, Ba sulphates and carbonates	Wet parts of production Installations Well completions
Ra scales	Ra-226, Ra-228, Ra-224 and their progeny	Sand, clay, paraffins, heavy metals	Separators, skimmer tanks
Condensates	Po-210	Unsupported	Gas production
Natural gas	Rn-222, Pb-210, Po-210	Noble gas, Plated on surfaces	Consumers domain, Gas treatment and Transport systems
Produced water	Ra-226, Ra-228, Ra-224 and/or Pb-210	More or less saline, large volumes in oil production	Each production facility



Figure (1)

Heavy scale formation in the lining of the oil pipeline (Statoil, 2007)



Figure 2

Sludge formations in the lining of the oil pipelines (Petroleum Recovery Services, 2010)

1.8 Research Problem

Exposure to the natural external background ionizing radiation in excess of certain lower limits involves significant health risks to humans and their environment (UNSCEAR, 2008; Pearce et al., 2012). Awali and Riffa Views gated communities are located in areas of extensive oil and gas industrial activities. These areas are expected to exhibit higher radiation levels compared to areas that lack any industrial activities that could alter the NORM.

1.8.1 Factors Affecting the Exposure to the Natural Background Radiation

The exposure to the natural background ionizing radiation is subjected to a wide variety of factors (UNSCEAR, 2008).

Altitude

The exposure to the ionizing radiation at higher altitudes, especially the cosmic rays, is greater than it is at lower altitudes (UNSCEAR, 2008). The atmosphere functions as a shield for many radiations that reach from extraterrestrial sources. As a result, the cosmic radiation is attenuated as it reaches lower altitudes (Museum of the Earth, 2011).

Latitude

The latitude of the Earth is an important consideration in terms of exposure to the ionizing radiation. Usually, people who live around the equator, even though they get most of the heat from the sun, generally they receive less cosmic radiation. The first reason is that the atmosphere around the equator is thicker than it is near the poles of the Earth. (UNSCEAR, 2008; CNSC, 2013). The second reason is the effect of the geomagnetism on the

distribution of the electrically charged ionizing radiation particles. Beta and alpha particles tend to deflect by the geomagnetic field towards the poles of the Earth according to their electrical charge (UNSCEAR, 2008; Museum of the Earth, 2011). Uncharged electromagnetic radiations, such as gamma rays do not possess an electrical charge hence, not affected by the geomagnetic field (UNSCEAR, 2008).

Geographical composition:

The geological features and the composition of the Earth's crust are also factors that affect the magnitude of the exposure to the ionizing radiation. Some regions in the world receive more terrestrial radiation from soils due to the presence of greater quantities of the Uranium, Thorium and Potassium radionuclides (CNSC, 2013). Terrestrial radiations are found around the globe in igneous and sedimentary rock (HPS, 2012).

Physical properties of the ionizing radiation:

The size of the ionizing radiation particles and their electrical charge play an important role in terms of exposure to radiation. Due to their electrical charge and relative large size, alpha and beta particles have smaller penetration abilities (UNSCEAR, 2008; CNSC, 2013). Therefore, these particles get absorbed by the rocks themselves and never escape to the air (UNSCEAR, 2008).

However, beta and alpha particles can be transported via dust and wind from one place to another. On the other hand, gamma rays are packets of energy called photons have neither mass nor electrical charge. They travel longer distances and have higher penetration abilities. Some of very high energy gamma rays are able to penetrate few centimeters of lead or concrete

(UNSCEAR, 2008). As a result, gamma rays can pass through the rocks causing a dose of external ionizing radiation to general public (Yehuwdah, 2012).

1.9 Research Objectives

The main objective of this study is to:

- Measure the natural external background ionizing radiation in Awali and Riffa Views and compare the findings to areas that have no industrial activities that could interfere with natural external background ionizing radiation.
- To establish a baseline spread and level of natural external background radiation in some areas in the Kingdom of Bahrain.

1.10 Research Significance

This study is the first ever attempt to study the level of natural external background ionizing radiation in the Kingdom of Bahrain. Baseline surveys yield important information in radiological environmental impact assessments. Performing radiological impact assessments help to delineate the locations of high ionizing radiation risks. The reason for that is to have better control on radiation pollution if the location of risk is known. Moreover, many countries have established regulations and guidelines to protect both workers and the general public from the NORM generated by non-nuclear industrial activities. Therefore, it is important to formulate local regulations and guidelines related industrial activities that could be sources of NORM.

1.11 Definition of Terms

- **Age Standardized cancer incidence Rate (ASR):** ‘is the number of new cancers of a specific site/type occurring in a specified population during a year, usually expressed as the number of cancers per 100,000 population at risk’ (NIH, 2016).
- **Alpha particles:** are types of ionizing radiation and they are positively charged molecule (IAEA, 2003).
- **Becquerel (Bq)** is the international unit of the radioactivity and it defines as the amount of ionizing radiation emitted per a radioactive decay (UNSCEAR, 2009).
- **Beta particles:** are types of ionizing radiation and they are negatively charged particles (IAEA, 2003).
- **Cosmic radiation:** consists of energetic particles or photons from beyond the solar system that strike the Earth’s atmosphere (UNSCEAR, 2008; Hendry et al., 2009).
- **Dolomitic limestone:** a type of rock that consists of 50% of dolomite. The dolomite is a sedimentary rock made mostly of the mineral dolomite, $\text{CaMg}(\text{CO}_3)_2$ (Geology.com, 2016).
- **Eocene:** ‘the second of five epochs in the Tertiary Period and the second of three epochs in the Paleogene. The Eocene lasted from about 55.8 to 33.9 million years ago’ (UCMP, 2009).
- **Gamma rays:** are electromagnetic photons emitted when the radioactive radionuclide undergoes alpha or beta decay (Museum of the Earth 2011).
- **Gray (Gy):** a unit of the absorbed dose and it is defined as one joule of energy deposited per kilogram of a mass (IAEA, 2003).

- **Half-life:** it is the time required for half of a radioactive atom to decay (UNSCEAR, 2000).
- **Histopathologist:** ‘a medical person who is specialized in the detection of the effect of a disease on body tissue who identify tumors by their histological characteristics’ (Merriam-Webster, 2016).
- **Histopathology:** ‘a medical examination involves a removal of body tissue to confirm or exclude malignancies’ (Merriam-Webster, 2016).
- **Ionizing radiation:** is the radiation that has the ability to produce ions as it passes through a matter (IAEA, 2003).
- **Linear No Threshold (LNT):** is a scientific principle states that even the smallest dose of radiation, no matter how small, involves a health risk to the humans (Morgan et al, 2009).
- **Naturally Occurring Radioactive Materials (NORM) or Technologically Enhanced Naturally Occurring Radioactive Material (TENORM):** consist of industrial activities that result in concentration of terrestrial radionuclides in their products, by-products or wastes (TENORM, 2014).
- **Non- stochastic effects:** are those effects that occur when certain threshold of exposure to the ionizing radiation is reached (UNSCEAR, 2000).
- **Pleistocene:** the time period that spanned from 2.6 million to 11,700 years ago (UCMP, 2009).
- **Produced water:** is naturally trapped water in oil and gas reservoirs and usually considered as a byproduct of oil and gas operations (EPA, 2015).

CHAPTER TWO

THEORETICAL FRAMEWORK LITERATURE OF REVIEW

2.1 Theoretical Framework

2.1.1 Cancer Incident in the Kingdom of Bahrain

2.1.2 Cancer Incident and Exposure to the Radiation

2.1.3 Oil and a Gas as a Source of Ionizing Radiation

2.2 Review of Literature

2.3 Research Hypothesis

CHAPTER TWO: THEORETICAL FRAMEWORK AND LITERATURE OF REVIEW

2.1 Theoretical Framework

This thesis hypothesis is to be investigated in three main aspects:

- 2.1.1 The pattern of cancer incidents in the kingdom of Bahrain
- 2.1.2 The relationship between the cancer incident and the exposure to ionizing radiation
- 2.1.3 Oil and gas exploration as a source of ionizing radiation

2.1.1 Cancer Incident in the Kingdom of Bahrain

A research performed by Al-hilli and Das (2010) to study the cancer pattern in the Kingdom of Bahrain between the years 1952 and 2004. Al-hilli is a Professor of pathology in the Arabian Gulf University and consultant histopathologist at Salmaniya Medical Complex. Al-hilli and Das (2010) gathered the required data from patients' archives in the histopathology and bone marrow hematology of the government, private hospitals and clinics in the Kingdom. The findings of their study showed that the cancer incidents in the Kingdom were increasing gradually and consistently from 12.05 per 100,000 citizens during 1952 and 1964 to 73.6 per 100,000 citizens during 1995-2004, (Figure 1) (Al-hilli and Das, 2010).

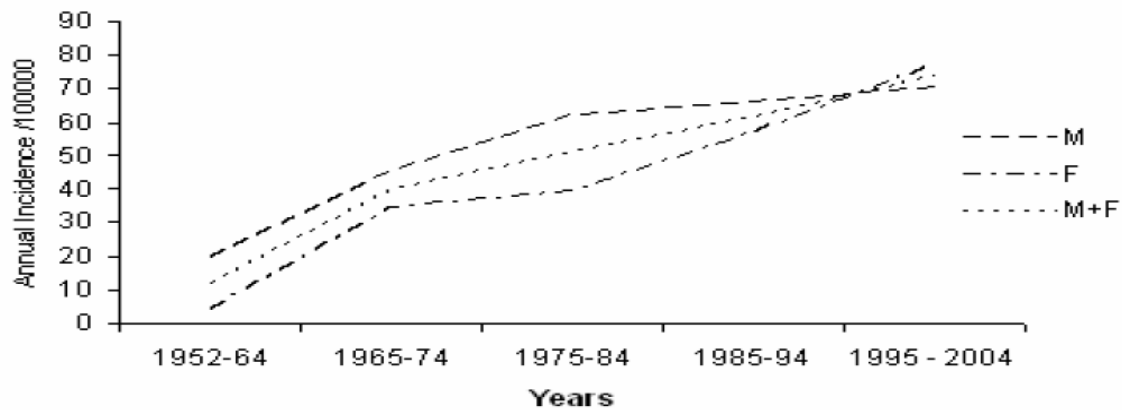


Figure (1)

The rate of cancer incidence in the Kingdom of Bahrain between 1952-2004 (Al-hilli and Das, 2010)

Another group of researchers headed by Al-Madouj et al (2011) from the Gulf Centre for Cancer Control & Prevention at the King Faisal Specialist Hospital & Research Centre carried out an important research that covers the cancer incidents for both males and females among the populations of the Gulf Cooperation Council (GCC) States between 1998 and 2007. The researchers found that the Bahraini male cancer sufferers have the highest average Age Standardized cancer incidence Rate (ASR) per 100,000 populations. The ASR of the Bahraini males was 158.5, followed by Qataris 153.4, then Kuwaitis 130.5, Omanis 92.5, UAE 82.3 and lastly, Saudi males with ASR of 72.5. Whereas in females, the highest ASR was found among Qatari women of 172.2 per 100,000 populations, followed by Bahraini women with ASR of 154.6, then Kuwaiti women 142.0, UAE women 95.1, Omani women 82.6, and the lowest incidence was among Saudi women with ASR of 71.2 per 100,000 populations (Figure 2).

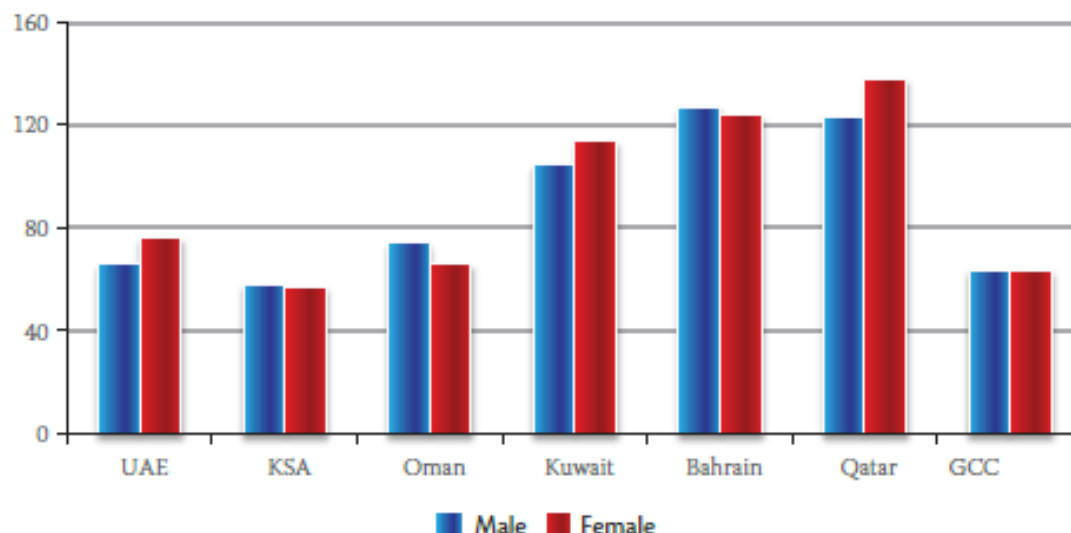


Figure (2)

Cancer ASR of in the GCC States between 1998– 2007 (Al-Madouj et al., 2011)

2.1.2 Cancer Incidents and Exposure to Radiation

One of the main causes of cancer development among the human beings is the exposure to the ionizing radiation (Dular, 2014). Exposure to the ionizing radiation in excess of certain lower limits can produce unacceptable deleterious effects in the humans and their environment (Dular, 2014; Pearce et al., 2012). The most accepted scientific principle according to the radiation protection standards states that even the smallest dose of radiation, no matter how small, involves health risks to the humans. This principle is called Linear No Threshold (LNT) hypothesis (Figure 3) (Morgan et al., 2009). Pearce et al. (2012) stated that presence of ionizing radiation, very much larger than background levels, can cause a measurable increase in cancers and leukemias after some years of delay.

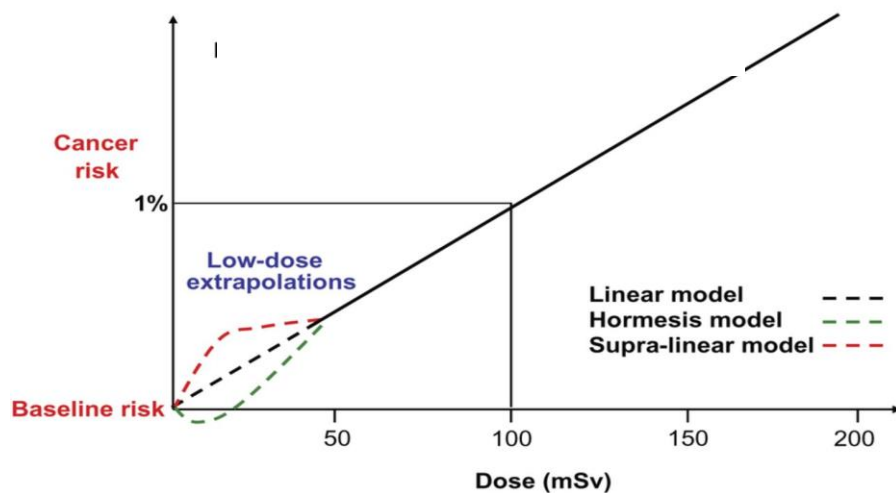


Figure (3)

Radiation Response Model; Linear No-Threshold (LNT) (Morgan et al, 2009)

2.1.3 Oil and Gas as a Source of Ionizing Radiation

According to the UNSCEAR (2009), oil and gas exploration activities result in concentration and enhancement of the Naturally Occurring Radioactive Materials (NORM). It occurs when radionuclides from underground formation brought to the Earth's surface. These radionuclides emit alpha, beta and gamma ionizing radiation.

It is, therefore, crucial to establish a reliable baseline data of natural background ionizing radiation levels of our surrounding environment. These data can be utilized for future environmental impact assessment and management by studying the origin, distribution, and transportation of radionuclides (Dular, 2014). In order to attain measurements targets, it is important to shed some light on some experiences of other studies.

2.2 Review of Literature

Hamilton et al (2004) performed a study in the United States of America to radiologically assess petroleum pipe scale from pipe-rattling operations. The exposure rate data were obtained for both the pre-cleaned pipes and the general area inhabited by workers during the descaling operation. During the study, the radiation exposure pathways of external exposure from un-cleaned pipes and from pipe scale dispersed on the ground were investigated. Data from three oil fields were collected to have as much industry representative data as possible. Hamilton et al (2004) found that the Radium specific activity from the pipe scale ranged from 33.6 ± 0.4 Bq/g to 65.5 ± 0.7 Bq/g, higher than the control area. In addition, the researchers found that workers annual external radiation dose from dispersed material was estimated to be 2.8 mSv/y for the operators and 4.1 mSv/y for the assistants.

Agbalagba et al (2013) performed another important study to assess the radiological impact of oil and gas exploration activities in the production area of the Delta State in Nigeria. A calibrated radiation meters and a Geographical Positioning System (GPS) were used in their study. Ten oil field facilities along with their host communities were investigated and evaluated. A total of 100 study points were measured and documented. The data analysis showed that the mean annual equivalent dose measured in oil field facilities ranged from 0.84 ± 0.34 mSv/y to 1.13 ± 0.44 mSv/y and from 0.61 ± 0.16 mSv/y to 1.12 ± 0.37 mSv/y in the host communities. The value obtained in the control study area was 0.48 ± 0.11 mSv/y. Agbalagba et al (2013) concluded that the radiation levels in some oil fields and their host communities exceeded the maximum radiation recommended limit which is 1 mSv/y. Agbalagba et al (2013) stated that the results obtained may not have an immediate health

hazard, but will pose some long-term health side effects on the staff working in the facilities and residents of the host communities.

In addition, Chad-Umoren and Briggs-Kamara (2010) assessed the ionizing radiation levels in the area of the Rivers State in the Niger Delta region, Nigeria. The radiation profile was measured using Mullard type ZP-1481 Geiger Muller survey meter. Chad-Umoren and Briggs-Kamara (2010) divided the State into three areas; the upland college campus (host communities); a collection of rural communities (control area) and a group of oil and gas industrial establishments (experimental areas). The results of the three sub-environments showed that the highest radiation equivalent dose was 1.33 ± 0.08 mSv/y occurred in the industrial zone while the lowest dose was 0.57 ± 0.16 mSv/y obtained from the rural sub-environment. The mean annual equivalent doses for the three areas were also calculated. The industrial sector showed the highest mean annual equivalent dose of 1.27 ± 0.09 mSv/y, followed by the upland college campus environment with mean annual equivalent dose of 0.75 ± 0.09 mSv/y. The rural riverine communities were having the lowest mean annual equivalent dose of 0.69 ± 0.17 mSv/y. According Chad-Umoren and Briggs-Kamara (2010) that their study revealed the following: Firstly, certain anthropogenic activities have altered the radiation levels of the environment. Secondly, the oil and gas industrial environment contributes most of the radiation levels to the State.

However, it is not applicable to attribute any abnormal high radiation measurements to anthropogenic intervention. Yet, there are some areas in the world are known to have high natural background ionizing radiation levels (UNSCEAR, 1993, 2000; Mohanty et al., 2004). For example, Ghiassi-nejad et al., (2002) performed a study to measure the natural background radiation in Ramsar, a city in Northern Iran. Ghiassi-nejad et al., (2002) found that people in some areas of Ramsar receive an annual radiation equivalent dose from natural background radiation up to 260 mSv/y. This is substantially higher than the 20 mSv/y permitted for radiation workers (Table 6). The researchers concluded that the elevation of the natural background radiation in Ramsar city was primarily due to the high concentration of Radium-226 and its decay products that are brought to the Earth's surface by hot springs. Hot springs in Ramsar city are used as spas by inhabitants and visitors (Ghiassi-nejad et al., 2002).

Table (1)
Areas of high levels of external natural background radiation in the world (Ghiassi-nejad et al., 2002)

Area, Country	Mean dose (mSv/y)	Maximum dose (mSv/y)	Minimum dose (mSv/y)
Ramsar, Iran	-	260	0.61
Kerala, India	-	35	1.75
Guarapari, Brazil	-	1.49	0.79
Yangjiang, China	3.24	-	-
Ireland	0.37	1.58	0.01
Austria	0.38	1.31	0.18
USA	0.41	1.03	0.12
World Average	0.50	0.82	0.16

From the theoretical framework and the literature review the following summery is drawn:

- The incidents of cancer in the Kingdom of Bahrain are increasing year by year.
- One of the main causes of cancer developments is exposure to ionizing radiation.
- Oil and gas industrial activities enhance the naturally occurring radioactive materials that consequently increase the exposure to the ionizing radiation.
- Areas of oil and gas industries exhibit higher radiation levels compared to areas that lack oil and gas activities.
- Some areas in the world exhibit a significant high natural background radiation levels due to some natural phenomenon.

The following points are valued and used in this study:

- Formulation of this study's hypothesis
- Collection of the correct information and data acquisition.
- Selections of the instrument and its specification.
- Critical thinking, reasoning and elaboration of the discussion.

2.3 Research Hypothesis

Awali and Riffa Views residential areas (experimental areas) are expected to exhibit higher radiation profile compared to areas that lack industrial activates that could alter NORM,I n this framework, Isa Town and Al-Budaiya Village were selected.

CHAPTER THREE

MATERIALS AND METHODS

- 3.1 Research study areas
- 3.2 Geological features
- 3.3 Research study tools
- 3.4 Measurement methodology
- 3.5 Data acquisition and conversions
- 3.5 Research data mapping

CHAPTER THREE: MATERIALS AND METHODS

3.1 Research Study Areas

In 1932 oil was discovered in the Kingdom of Bahrain. The subsequent exploration of the oil and gas has been concentrated largely in the central part of the Kingdom. The central part of the Kingdom contains a maze of oil pipelines, wellheads, sumps, and numerous other oil-field installations (Doornkamp, 1980) (Figures 4 and 5). Awali and Riffa Views residential areas are located in the center of the Kingdom where there are extensive oil and gas operations and transportations. Hence, residents in these areas are expected to expose to higher radiation levels comparing to other areas. These areas were selected intentionally as experimental areas.



Figure (1)

Oil pipelines and other installations in Awali and Riffa Views



Figure (2)

Oil pipelines in Awali and Riffa Views

Awali is a small municipality located approximately to the center of the Kingdom of Bahrain, (Figure 6). It is populated mostly by workers of various nationalities from around the world who skills were needed in setting up and running the refinery (Willis, 1967). Additionally, Awali hosts the Awali Hospital, Bapco Club, a mosque, a church and the Princess Sabeeka Park. East to Awali, a very recently developed gated community called Riffa Views (Figure 6) (Maps.google.com, 2015). In addition to the residents, Riffa Views host a mega mart, a school and golf clubs. The current indicators showing that these two residential areas are going to be become more and more populated.

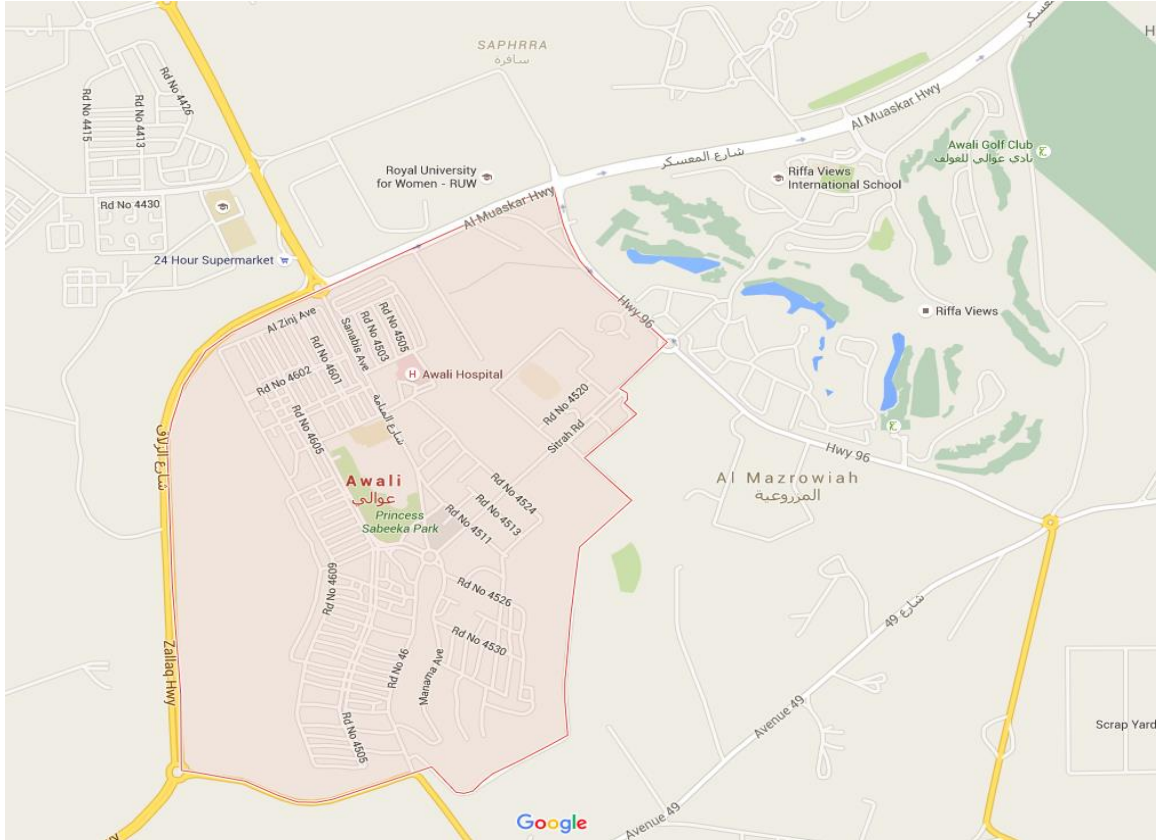


Figure (3)
Outline of Awali and Riffa Views, Kingdom of Bahrain
(Maps.google.com, 2015)

Another two residential areas were intentionally selected, namely, Isa Town and Al-Budaiya Village. Isa Town lies north to Awali, about 8 km. Isa Town lacks any major industrial activities that may contribute to NORM (Figure 7). AL-Budaiya Village is a small coastal village lies on the northwestern coast of the Kingdom of Bahrain. Similarly, AL-Budaiya Village lacks any major industrial activates that may alter the NORM (Figure 8).

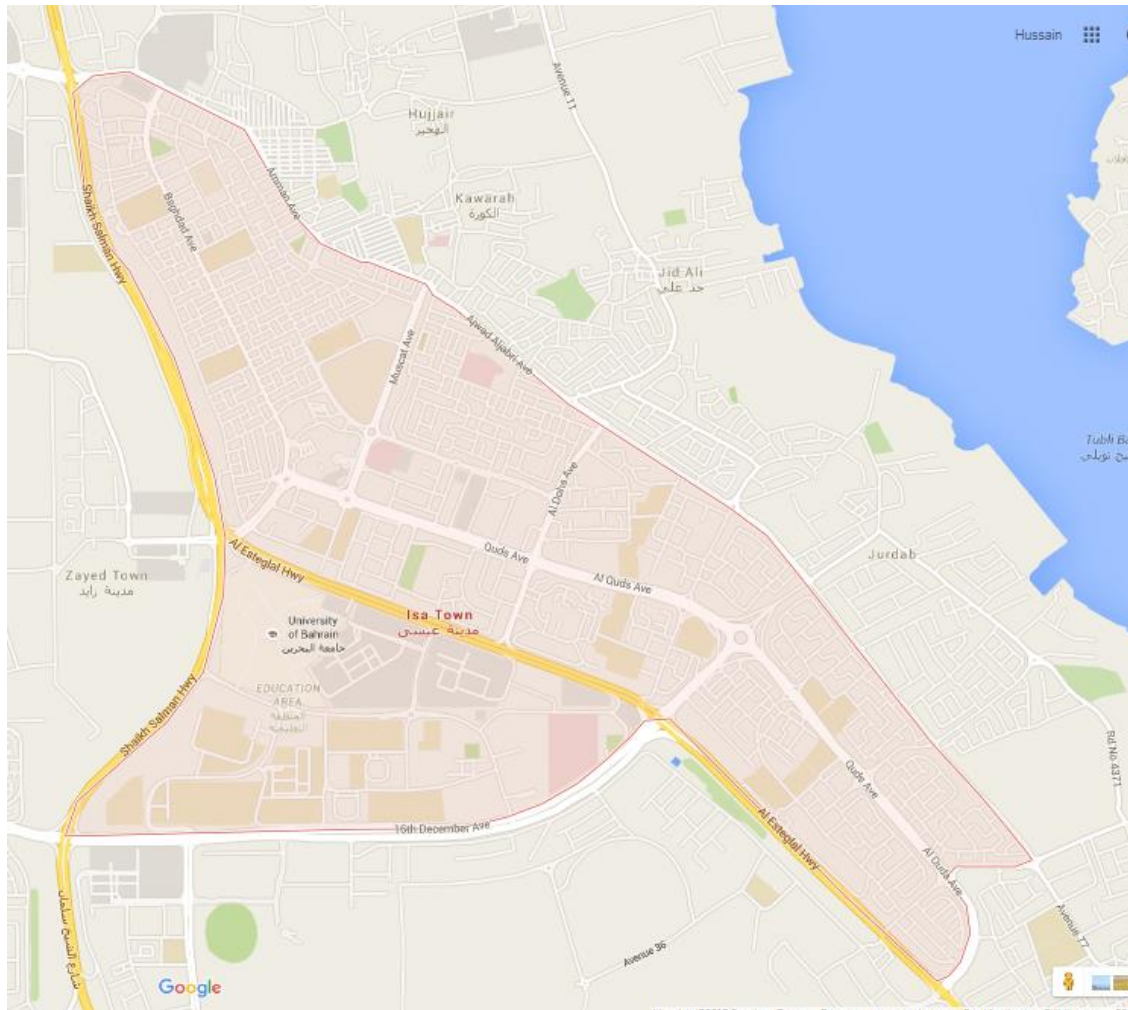


Figure (4)
Isa Town, Kingdom of Bahrain (Maps.google.com)

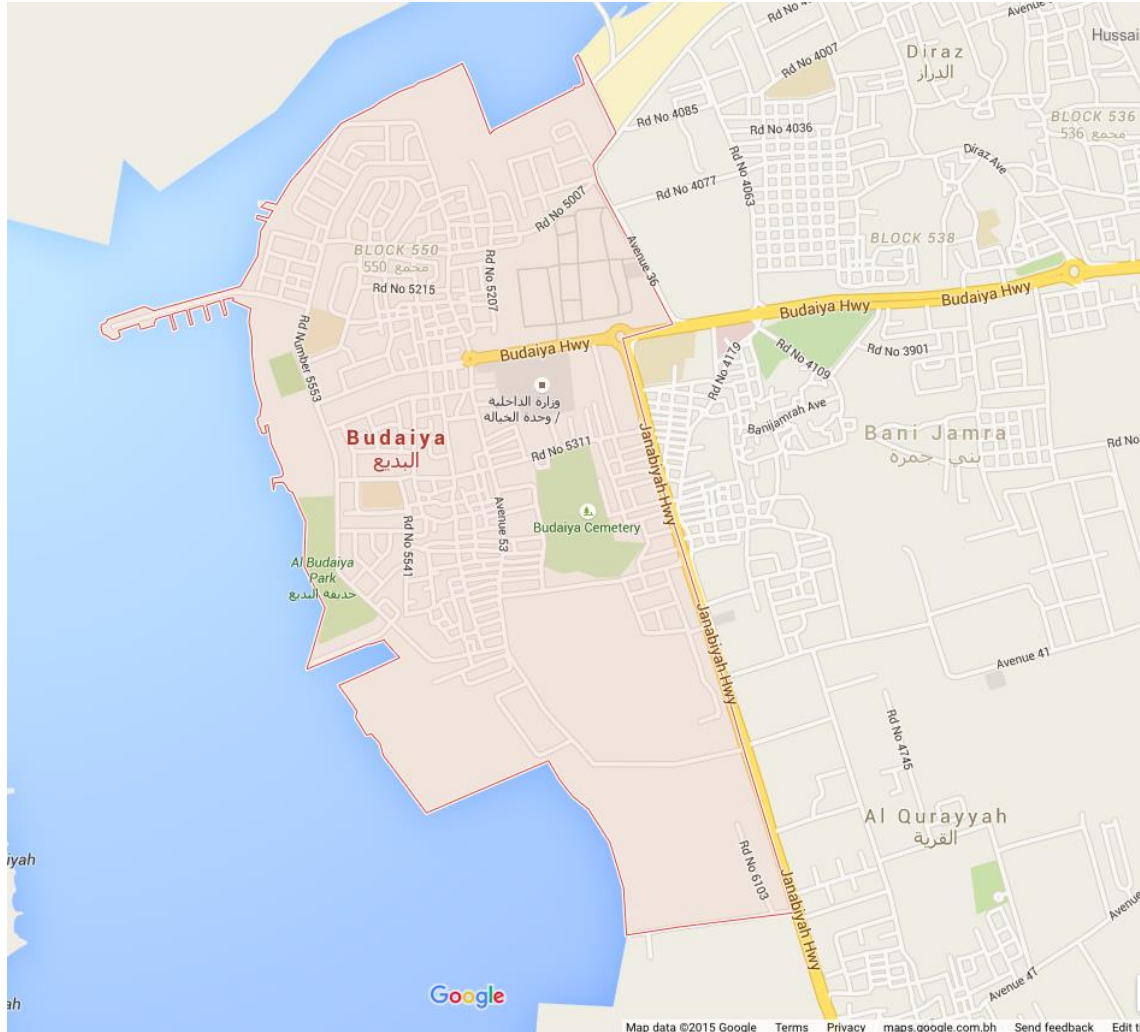


Figure (5)

Al-Budaiya Village, Kingdom of Bahrain (Maps.google.com)

3.2 Geological Features

The main land of the Kingdom of Bahrain is dominated by an elongated domal structure of Eocene sediments (Figure 9). The Eocene sediments are surrounded by flat lying superficial deposits of Pleistocene and Recent age. Most of the exposed bedrocks on the Kingdom consist of either limestone or dolomite (Doornkamp, 1980). The lithology of Awali and Riffa Views composed of Rus Formation, more specifically, Awali Carbonate Formation. This is the oldest formation outcropping on the Kingdom of Bahrain and it

occurs only in the central part of Kingdom. The rocks in this formation are almost consisting of equiangular, fine grained to medium grained, chert-bearing dolomitic limestones with small but variable amounts of quartz and clay minerals (Figure 10). The main components of the clay beds are quartz, attapulgite, feldspars, micas, halite and gypsum (Willis, 1967; Doornkamp, 1980).

The lithology of Isa town is composed mainly of Dammam Formation, particularly Al Buhayr Carbonate Formation. This formation is predominantly laminated, rusty, yellow-orange argillaceous dolosilite and sometime may contains clay pockets. Moreover, the surface of Isa town consists of gravel, sand and silts (Figure 11) (Willis, 1967; Doornkamp, 1980).

The northern west coastal side of the Kingdom of Bahrain in which Al-Budaiya Village is located has been given a little scientific description. However, the surface of this area is covered mostly by sand, silts and gypseous quartzose sand. Rarely, in some areas of Al Budaiya, a thinly veneered bedrocks crop out on the surface (Doornkamp, 1980).

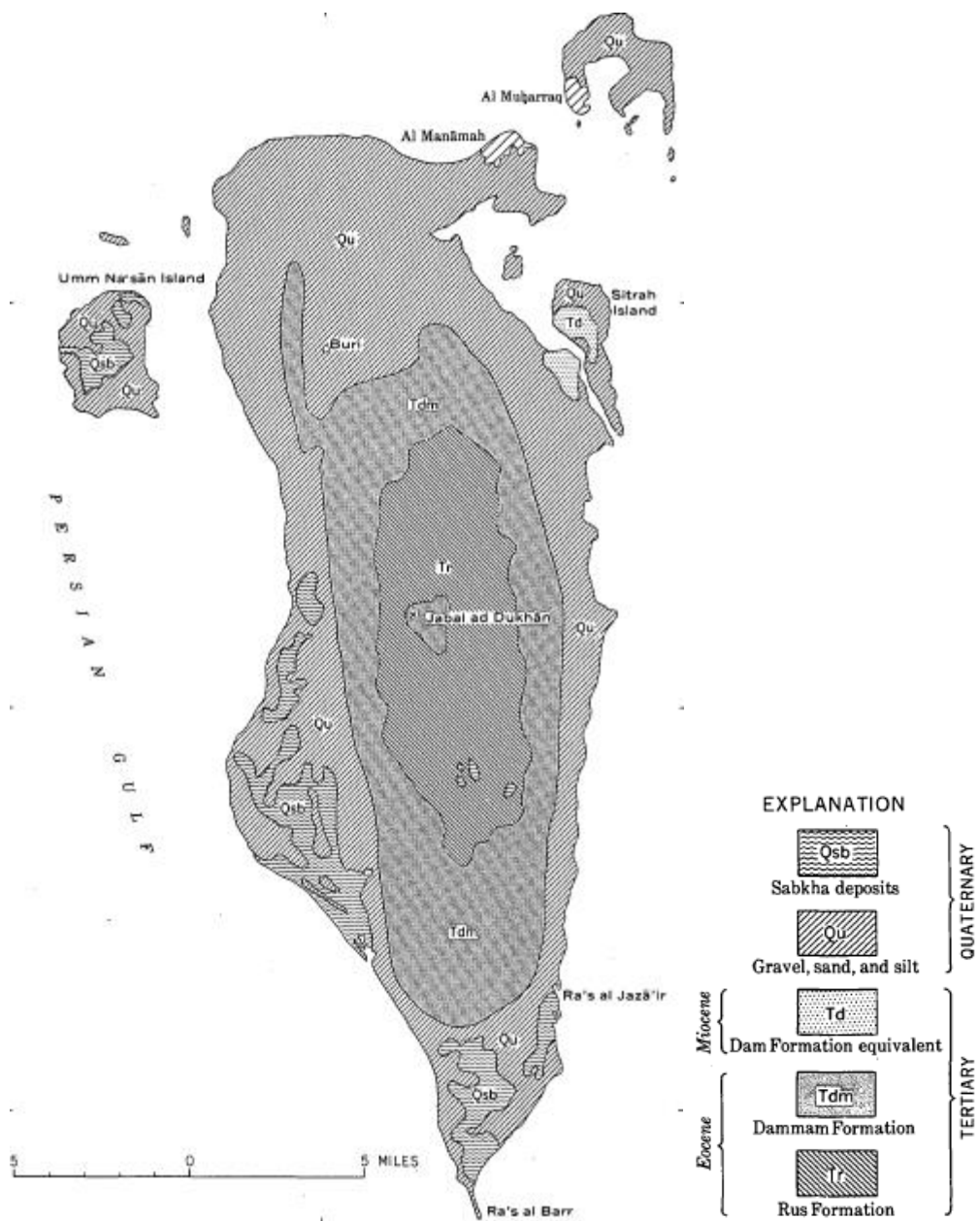


Figure (6)
Geographical map of the Kingdom of Bahrain (Willis, 1967)

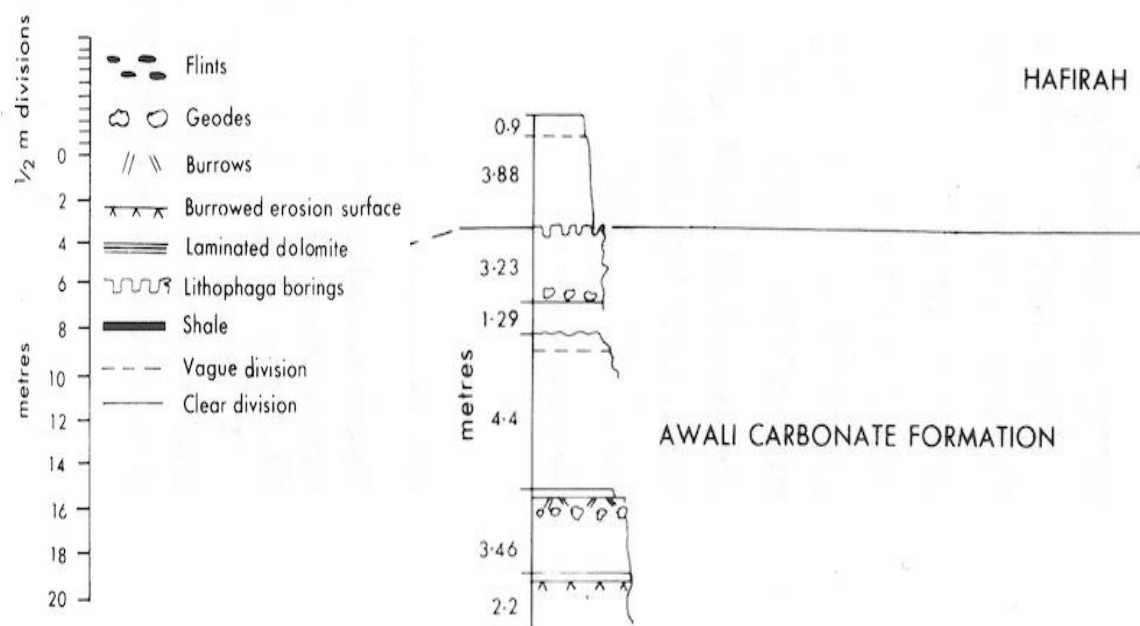


Figure (7)

The lithology of Awali and Riffa Views (Doornkamp, 1980)

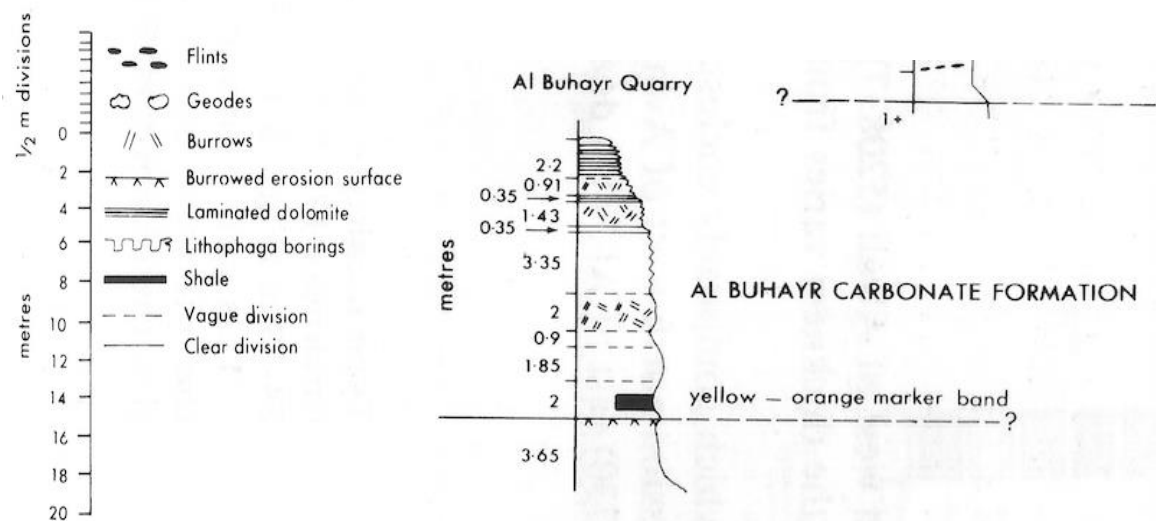


Figure (8)

The lithology of Isa Town (Doornkamp, 1980)

3.3 Research Study Tools

The natural external background gamma radiation measurements were acquired using a hand-held gamma-ray detection system called Colibri Very Low Dose (VLD) radiation survey meter (Figure 12). This survey meter has been used by TEPCO employee to map areas affected by Fukushima nuclear disaster in June, 2011 (Canberra, 2015).



Figure (9)

The Colibri Very Low Dose radiation survey meter

Colibri VLD radiation survey meter has the following specifications (Appendix I) (Canberra, 2015):

- Capable of measuring precisely and quickly background level of dose rate changes
- Colibri VLD is based on a Cesium Iodide (CsI) scintillator with a novel energy compensation technique that improves sensitivity over entire energy range.

- Allows measurement of very low dose-rate starting from 10 nSv to 1 mSv.
- Incorporates a scaler timer mode that allows user to select an integration time from 1 second to 255 seconds and therefore, improves Minimum Detectable Activity (MDA). It displays the number of counts for the selected period of time and the average value in selected unit. However, the dose-rate is automatically stored every five seconds.
- The automatic data-logging function stores up to 60,000 records of 1 to 255 seconds acquisition with time interval of 0 to 200,000 seconds.
- Perfect instrument for mapping applications. It can save a large number of measurements associated with location data, such as GPS coordinates.
- Moreover, the system has comprehensive Personal Computer (PC) software for data analysis and mapping applications.

3.4 Measurement Methodology

Colibri VLD survey meter was calibrated by the manufacturer on the 26th August 2015 using Cesium 137 (Cs-137) source. The data acquisition of the four studied areas performed during June, 2015 and September, 2015. Firstly, the survey meter was mounted on a vehicle at height of one meter above the ground. Then the vehicle was driven for every 300 meters and then stopped to acquire the radiation measurement. Before acquiring the radiation measurements, the meter's GPS was enabled so that every measurement is acquired along with its satellite coordinates. Each radiation measurement was acquired for 10 seconds as recommended by the manufacturer of the meter. The vehicle was driven to cover the motorway, interior roads and streets of each studied area. In addition, a photo was obtained using a digital camera for

any area that shows a high reading to document any oil and gas installations around the area.

3.5 Data Conversions

The conversion of the units of the natural external background ionizing radiation was performed using Microsoft Office Excel 2010. The acquired data were firstly downloaded from the survey meter onto the PC using Colibri Software. The downloaded values of the external background radiation were originally in the unit of Sievert per hour ($\mu\text{Sv/h}$). To convert these values from Sv/h to milliSievert per year (mSv/y), the following conversion factor was used (Hainke, 2005):

$$1\text{mSv/yr} = 365 \times 24 \times 10^{-3}\mu\text{Sv/hr}$$

Moreover, Microsoft excel 2010 was used to calculate the mean equivalent doses and their Standard Deviation (SD). Obtaining the units in mSv/y allow for a direct comparison of this research results with the literature and the ICRP-60 standards. The standard deviation is used to demonstrate how far the measured data are deviate from the mean data. All values were then rounded to two decimal places to have better data representation. The survey meter software stores the data originally in the format of Excel CSV. To make these data format compatible with Google Map Macro, they firstly converted into Excel Macro Enabled-Workbook using Microsoft Excel 2010. Finally, they were uploaded onto Google Map Macro and subsequently generated maps that had the locations and values of the radiation measurements.

3.6 Research Data Mapping

The mapping of the natural external background radiation values was performed using Google Map Macro online application. Google Map Macro allows users to insert specific locations and values with full drag and navigation abilities (Jive community, 2010). Once the calculations and conversions of the original data were performed, each area was uploaded onto Google Map Macro separately. The maps of each area were then generated and snapped.

CHAPTER FOUR

RESEARCH STUDY'S RESULTS, DISCUSSION, AND RECOMMENDATIONS

4.1 Review of Research Study's Results

4.1.1 Control Areas

4.1.2 Experimental Areas

4.2 Discussion

4.3 Conclusion and Recommendation

4.4 Suggestion for Further Research

CHAPTER FOUR: RESEARCH STUDY'S RESULTS, DISCUSSION, AND RECOMMENDATIONS

4.1 Preview of Research Study's Results

In this study, a very low dose radiation survey meter 'Colibri' was used to measure the natural external background ionizing radiation in the Kingdom of Bahrain. The measurements were acquired at every 300 meters intervals and at a height of 1 meter. The radiation survey meter stores the acquired data originally in the unit of $\mu\text{Sv/h}$. These data were then converted to mSv/y using the following conversion factor (Hainke, 2005):

$$1\text{mSv/yr} = 365 \times 24 \times 10^{-3}\mu\text{Sv/hr}$$

4.1.1 Isa Town and Al-Budaiya

Isa Town and Al-Budaiya Village were intentionally selected due to lack any industrial activities that could interfere with Naturally Occurring Radioactive Materials (NORM). Isa Town was the first studied area. 122 measurements were obtained to cover the entire area of the Town. The acquired values and their correspondent GPS coordinates for Isa Town are shown in Table 7. The data analysis reveals that the radiation dose rates in this area range from a minimum value of $0.02 \mu\text{Sv/h}$ to a maximum value of $0.19 \mu\text{Sv/h}$. The calculated mean radiation dose rate in Isa Town is $0.09 \pm 0.04 \mu\text{Sv/h}$. Figure 13, demonstrates the distribution and mapping of the radiation values in the Town in $\mu\text{Sv/h}$.

Table (1)
Radiation dose rates and their GPS coordinates in Isa Town

No.	Latitude	Longitude	(μ Sv/h)	No.	Latitude	Longitude	(μ Sv/h)
1	26.159792	50.538362	0.09	62	26.158003	50.572225	0.06
2	26.161893	50.540725	0.16	63	26.160258	50.570172	0.13
3	26.165017	50.54297	0.08	64	26.162118	50.56846	0.14
4	26.16858	50.544268	0.18	65	26.163628	50.569008	0.05
5	26.170905	50.54285	0.14	66	26.16235	50.57047	0.08
6	26.177812	50.540038	0.07	67	26.165033	50.5674	0.18
7	26.177792	50.540028	0.05	68	26.166643	50.568263	0.14
8	26.180052	50.538545	0.10	69	26.166135	50.566492	0.13
9	26.182832	50.537415	0.07	70	26.163515	50.5635	0.14
10	26.185538	50.536993	0.04	71	26.159713	50.55899	0.09
11	26.186628	50.539747	0.11	72	26.158153	50.555675	0.12
12	26.185773	50.541863	0.08	73	26.157738	50.552597	0.08
13	26.184773	50.54412	0.10	74	26.157797	50.54989	0.04
14	26.182082	50.545828	0.02	75	26.157817	50.547242	0.04
15	26.180095	50.547582	0.02	76	26.15753	50.54394	0.07
16	26.179235	50.550567	0.13	77	26.157678	50.540948	0.05
17	26.177825	50.553088	0.07	78	26.159483	50.540725	0.12
18	26.175573	50.555947	0.04	79	26.159607	50.543565	0.08
19	26.174275	50.557873	0.07	80	26.161605	50.545593	0.11
20	26.172905	50.56019	0.03	81	26.160605	50.548532	0.06
21	26.171165	50.563013	0.12	82	26.160852	50.551053	0.05
22	26.169563	50.56557	0.07	83	26.1619	50.552627	0.05
23	26.167773	50.567747	0.10	84	26.159937	50.554887	0.14
24	26.165867	50.569427	0.09	85	26.162187	50.555445	0.17
25	26.163582	50.571353	0.10	86	26.162165	50.558358	0.14
26	26.161298	50.573362	0.10	87	26.162668	50.551395	0.04
27	26.15931	50.575192	0.12	88	26.163653	50.551445	0.19
28	26.157382	50.577122	0.08	89	26.16209	50.548577	0.15
29	26.15626	50.576893	0.07	90	26.162635	50.544723	0.12
30	26.152337	50.574833	0.06	91	26.163698	50.542452	0.11
31	26.152678	50.572657	0.09	92	26.157635	50.53962	0.11
32	26.154603	50.570533	0.07	93	26.157673	50.537267	0.12
33	26.158458	50.566252	0.11	94	26.1754473	50.5411261	0.04
34	26.15846	50.56625	0.06	95	26.171655	50.549182	0.05
35	26.16034	50.56414	0.04	96	26.173727	50.54993	0.08
36	26.162768	50.560853	0.05	97	26.1780784	50.5516821	0.04
37	26.163657	50.558552	0.17	98	26.175897	50.551137	0.07
38	26.164537	50.556018	0.09	99	26.174845	50.553695	0.07
39	26.16537	50.553243	0.15	100	26.173762	50.556778	0.16
40	26.16637	50.55014	0.19	101	26.173033	50.559037	0.06
41	26.167567	50.546393	0.15	102	26.171352	50.55785	0.04
42	26.1731299	50.5420492	0.09	103	26.171002	50.556117	0.11

Continued, Table (7)

Radiation dose rates and their GPS coordinates in Isa Town

No.	Latitude	Longitude	(μSv/h)	No.	Latitude	Longitude	(μSv/h)
43	26.170167	50.545352	0.1	104	26.171838	50.553145	0.06
44	26.170425	50.547772	0.15	105	26.172755	50.550445	0.15
45	26.169503	50.551025	0.16	106	26.1774961	50.548693	0.08
46	26.16857	50.554207	0.09	107	26.17004	50.557178	0.09
47	26.167703	50.557085	0.03	108	26.16833	50.556555	0.07
48	26.167023	50.55945	0.09	109	26.167812	50.56369	0.08
49	26.166282	50.562658	0.09	110	26.16913	50.5616	0.08
50	26.165067	50.564877	0.13	111	26.167683	50.56134	0.09
51	26.163368	50.566953	0.11	112	26.168743	50.559172	0.09
52	26.163368	50.566953	0.07	113	26.171283	50.560392	0.04
53	26.16244	50.566887	0.01	114	26.174707	50.54763	0.12
54	26.16093	50.566018	0.11	115	26.177357	50.546187	0.11
55	26.161282	50.564573	0.16	116	26.179685	50.544932	0.14
56	26.158172	50.568313	0.07	117	26.182543	50.543298	0.16
57	26.1562686	50.5684639	0.05	118	26.185503	50.540258	0.07
58	26.15701	50.571472	0.09	119	26.182673	50.540512	0.09
59	26.158885	50.57051	0.06	120	26.179627	50.542198	0.04
60	26.157175	50.572745	0.04	121	26.176958	50.54355	0.06
61	26.155008	50.574722	0.09	122	26.174758	50.544803	0.03

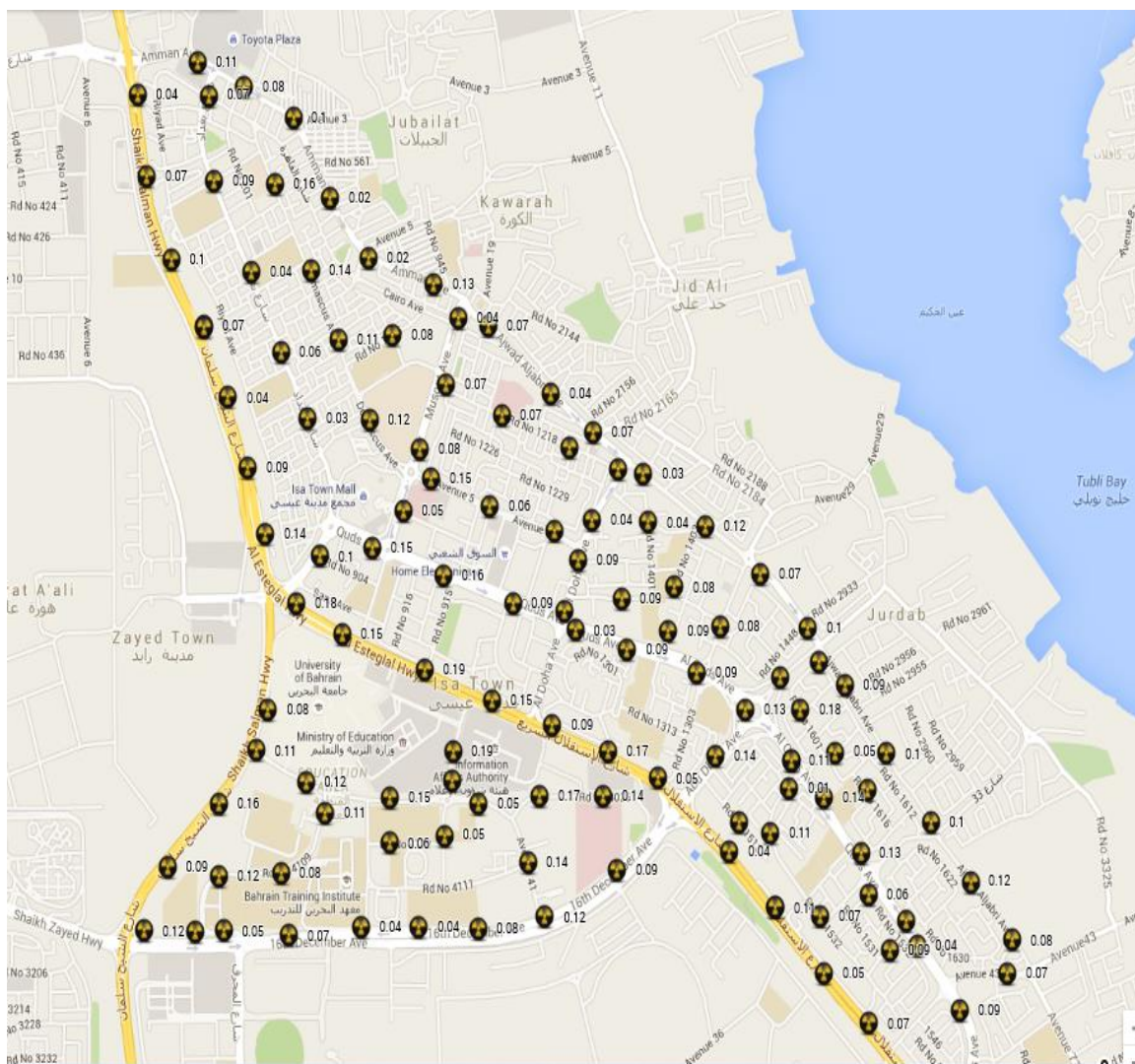


Figure (1)
Mapping of the radiation dose rates in Isa Town in $\mu\text{Sv/h}$

The second area was Al-Budaiya Village. As can be seen from Figure 14, about 47 measurements were acquired to cover the entire area of the Village. These values demonstrate fairly uniform distribution of low radiation levels. The results indicate that the radiation dose rates in Al-Budaiya range from a minimum value of $0.03 \mu\text{Sv/h}$ to a maximum value of $0.17 \mu\text{Sv/h}$. The mean radiation dose rate measured in Al-Budaiya Village is $0.08 \pm 0.03 \mu\text{Sv/h}$. Table 8 demonstrates the radiation profile of the Village.

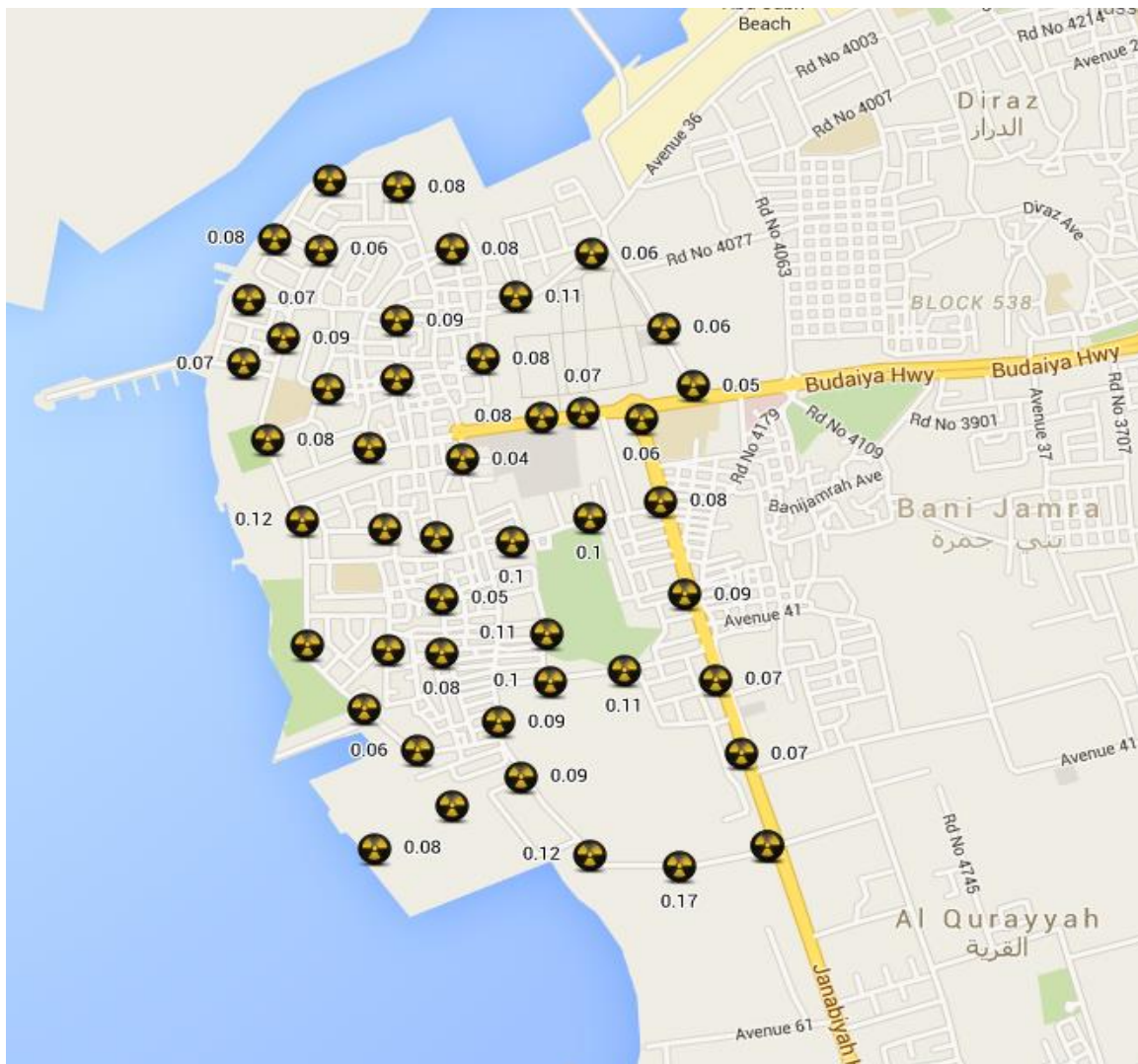


Figure (2)

Mapping of the radiation dose rates in Al-Budaiya Village in $\mu\text{Sv/h}$

Table (2)**Radiation dose rates and GPS coordinates in Al-Budaiya Village**

No.	Latitude	Longitude	($\mu\text{Sv/h}$)	No.	Latitude	Longitude	($\mu\text{Sv/h}$)
1	26.203273	50.458692	0.09	25	26.21486	50.449555	0.06
2	26.202953	50.45548	0.17	26	26.21486	50.449555	0.11
3	26.204098	50.453482	0.12	27	26.21486	50.449555	0.08
4	26.204947	50.452567	0.09	28	26.21486	50.449555	0.07
5	26.20425	50.450812	0.08	29	26.21486	50.449555	0.04
6	26.203218	50.448898	0.08	30	26.217602	50.4543	0.03
7	26.204883	50.450965	0.09	31	26.216565	50.452435	0.04
8	26.206593	50.448652	0.07	32	26.213658	50.453078	0.05
9	26.208128	50.447247	0.07	33	26.213757	50.454108	0.08
10	26.211157	50.447092	0.12	34	26.212623	50.451095	0.08
11	26.214788	50.445708	0.07	35	26.210938	50.449178	0.1
12	26.214812	50.445665	0.15	36	26.210772	50.450465	0.11
13	26.214813	50.445662	0.08	37	26.209257	50.450577	0.11
14	26.216498	50.445753	0.07	38	26.208025	50.449265	0.07
15	26.217955	50.446428	0.08	39	26.20795	50.450592	0.06
16	26.219362	50.447777	0.09	40	26.207257	50.453278	0.08
17	26.219213	50.449518	0.08	41	26.208408	50.453183	0.1
18	26.217705	50.450838	0.08	42	26.207507	50.455138	0.1
19	26.217695	50.447562	0.06	43	26.207937	50.456983	0.06
20	26.215563	50.446637	0.09	44	26.213607	50.455537	0.11
21	26.215978	50.449468	0.09	45	26.211608	50.45604	0.08
22	26.21486	50.449555	0.07	46	26.211215	50.454258	0.07
23	26.21486	50.449555	0.1	47	26.210625	50.452353	0.04
24	26.208538	50.457033	0.09				

4.1.2 Experimental Areas

Two areas were selected intentionally as experimental areas namely, Awali and Riffa View residential areas. These areas are believed to be impacted radiologically as a consequence of oil and gas operations.

Regarding Awali residential area, the radiation values of 60 measurements are shown Table 9. The minimum radiation dose rate measured in Awali is 0.11 $\mu\text{Sv/h}$ while the maximum measurement is 0.37 $\mu\text{Sv/h}$. However, the overall mean radiation dose rate in Awali area is 0.24 ± 0.08 $\mu\text{Sv/h}$.

Table (3)**Radiation dose rates and their GPS coordinates of Awali**

No.	Latitude	Longitude	($\mu\text{Sv/h}$)	No.	Latitude	Longitude	($\mu\text{Sv/h}$)
1	26.0916239	50.5434722	0.19	31	26.0874484	50.5578208	0.29
2	26.0813382	50.5529584	0.35	32	26.0854309	50.5438602	0.18
3	26.0904735	50.5486888	0.20	33	26.0914501	50.5454791	0.32
4	26.083403	50.549567	0.33	34	26.0790195	50.5484612	0.32
5	26.080822	50.549382	0.37	35	26.0779666	50.5460475	0.29
6	26.0937345	50.5492949	0.13	36	26.0856224	50.5496141	0.28
7	26.09678	50.547437	0.14	37	26.0833098	50.5448998	0.30
8	26.0974176	50.5458388	0.11	38	26.0816385	50.5471244	0.30
9	26.0949078	50.5580858	0.19	39	26.0848271	50.5527651	0.31
10	26.0802273	50.5447173	0.20	40	26.0827877	50.5545241	0.29
11	26.0865268	50.5512168	0.25	41	26.0850023	50.5547159	0.31
12	26.0783674	50.5434316	0.25	42	26.0792242	50.5524373	0.31
13	26.085365	50.5395266	0.19	43	26.0782091	50.5505522	0.37
14	26.0819543	50.5399404	0.24	44	26.0808385	50.5545238	0.32
15	26.0851993	50.5473016	0.30	45	26.0982938	50.5525538	0.24
16	26.0871576	50.5450238	0.13	46	26.0834926	50.5519473	0.37
17	26.0878722	50.5418728	0.12	47	26.0934616	50.5563608	0.24
18	26.0892295	50.5441024	0.18	48	26.0914553	50.5502617	0.20
19	26.0931245	50.5425137	0.17	49	26.0886229	50.5535777	0.30
20	26.0967801	50.5435382	0.15	50	26.1007593	50.5540056	0.16
21	26.0956665	50.5415951	0.13	51	26.0914975	50.5543796	0.30
22	26.0908009	50.5394058	0.15	52	26.0999356	50.5510101	0.19
23	26.0978785	50.5555141	0.21	53	26.0989345	50.5491888	0.12
24	26.0933457	50.5397158	0.15	54	26.0966233	50.5500666	0.26
25	26.0949042	50.5449863	0.15	55	26.0947547	50.5512369	0.19
26	26.088273	50.53947	0.16	56	26.0898786	50.5560812	0.33
27	26.0876394	50.5472426	0.22	57	26.0951343	50.5549107	0.27
28	26.0790361	50.5405259	0.22	58	26.0931914	50.5520856	0.12
29	26.0894512	50.5461422	0.25	59	26.0900283	50.5520986	0.33
30	26.0936906	50.5464287	0.27	60	26.088678	50.550396	0.17

The spread of the natural external background radiation in Awali seems to be non-homogenous as shown in Figure 15. The mapping of Awali radiation values shows that the south and southeastern Awali exhibit higher radiation levels compared to north and northwestern Awali. The radiation dose rates of the south and southeastern Awali range from a minimum value of 0.16 $\mu\text{Sv/h}$ to a maximum value of 0.37 $\mu\text{Sv/h}$ averaged to 0.34 ± 0.09 $\mu\text{Sv/h}$ (Figure 16). On the other hand, the rest parts of Awali demonstrate

fairly lower radiation levels. The mean radiation dose rate of the north and northwestern Awali is $0.18 \pm 0.06 \mu\text{Sv/h}$ (Figure 16). As expected, areas of highest radiation readings in Awali were acquired near some old oil fields and oil pipelines installations. These installations are scattered around residents' accommodation as can be seen in Figures 17, 18 and 19.

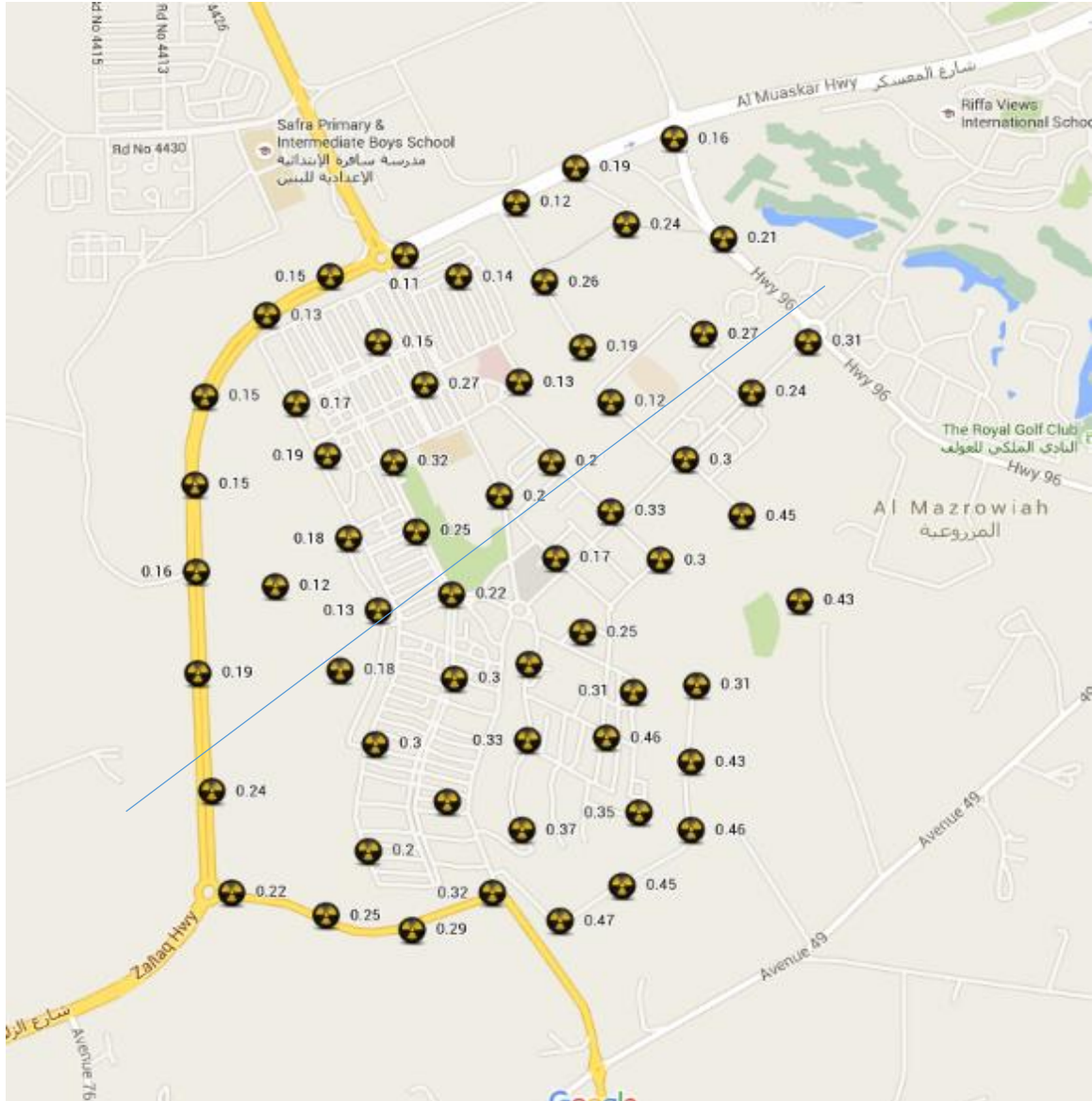


Figure (3)

Mapping of the radiation dose rates in Awali in $\mu\text{Sv/h}$

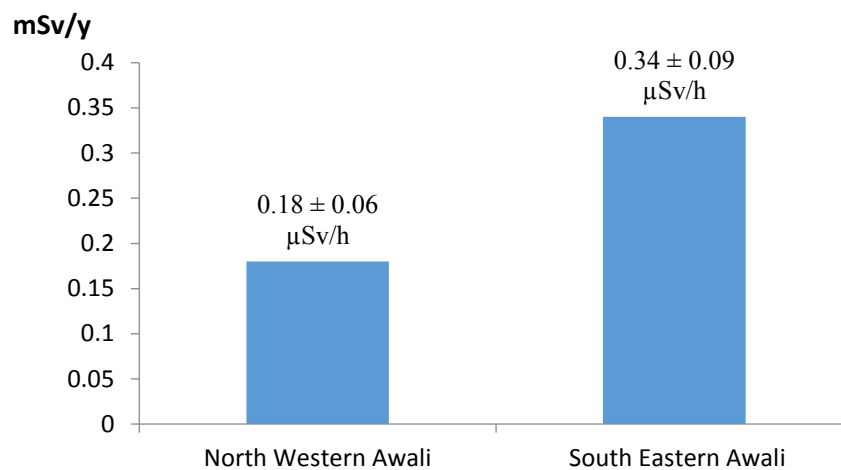


Figure (4)

Radiation dose rates of the North Western and south Eastern Awali in ($\mu\text{Sv/h}$)



Figure (5)

Oil pipeline installations in Southeastern Awali



Figure (6)

Oil pipeline installations in Southeastern Awali

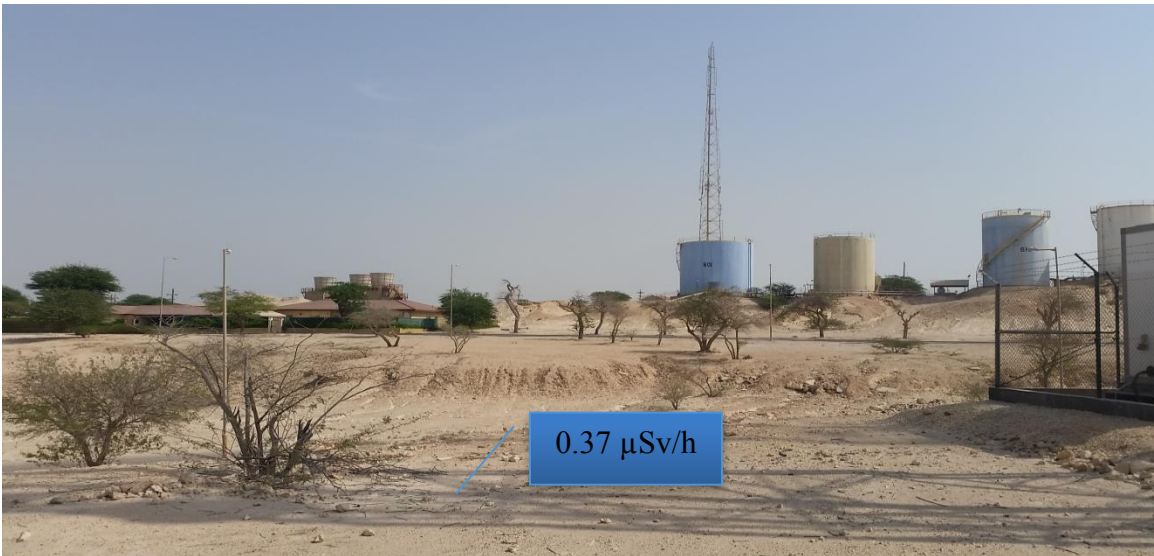


Figure (7)

Area of the highest radiation readings in Southeastern Awali

Concerning the second experimental area, the Riffa Views, about 88 radiation measurements were acquired using Colibri VLD survey meter (Table 10). The data analysis shows that the radiation dose rates of the Riffa Views range from a minimum value of $0.10 \mu\text{Sv/h}$ to a maximum value of

0.30 $\mu\text{Sv/h}$. However, the overall mean annual radiation dose rate in Riffa Views is $0.15 \pm 0.05 \mu\text{Sv/h}$.

Table (4)

Radiation dose rates and their GPS coordinates in Riffa Views

No.	Latitude	Longitude	($\mu\text{Sv/h}$)	No.	Latitude	Longitude	($\mu\text{Sv/h}$)
1	26.0919915	50.5622882	0.29	45	26.092248	50.564225	0.16
2	26.0935668	50.5630261	0.16	46	26.093245	50.565645	0.21
3	26.1006173	50.5621073	0.18	47	26.0952651	50.5647881	0.12
4	26.0919127	50.5739722	0.24	48	26.0946819	50.5631869	0.16
5	26.1028958	50.5669684	0.22	49	26.09399	50.561298	0.12
6	26.1022075	50.5638138	0.15	50	26.0949278	50.562116	0.12
7	26.0893576	50.5704613	0.18	51	26.1027417	50.5654643	0.12
8	26.0999155	50.5630183	0.15	52	26.1013229	50.5665492	0.12
9	26.0999577	50.5644202	0.17	53	26.0995653	50.567162	0.16
10	26.0927369	50.5608908	0.23	54	26.0980195	50.5674687	0.12
11	26.0997252	50.5542592	0.11	55	26.1002006	50.5663604	0.13
12	26.101015	50.554075	0.10	56	26.09893	50.5655587	0.17
13	26.0988925	50.5547402	0.30	57	26.0987394	50.5636016	0.20
14	26.098033	50.555248	0.19	58	26.10185	50.560027	0.12
15	26.0971649	50.5561205	0.29	59	26.101613	50.558738	0.12
16	26.0964448	50.5569929	0.24	60	26.099208	50.562208	0.17
17	26.0954495	50.5579834	0.21	61	26.0982105	50.561535	0.11
18	26.0946237	50.5588559	0.13	62	26.096117	50.56053	0.11
19	26.0941154	50.5594923	0.17	63	26.097085	50.559695	0.14
20	26.0935226	50.560129	0.15	64	26.097155	50.559175	0.12
21	26.09132	50.5641847	0.23	65	26.100705	50.56537	0.13
22	26.0908544	50.5658118	0.13	66	26.1036369	50.5680522	0.11
23	26.0898328	50.569232	0.15	67	26.1060114	50.5700164	0.14
24	26.088707	50.571752	0.13	68	26.105948	50.5711955	0.15
25	26.1021102	50.5718412	0.18	69	26.1037674	50.5701342	0.14
26	26.088597	50.572925	0.10	70	26.104847	50.570127	0.10
27	26.090747	50.573785	0.13	71	26.104248	50.570772	0.11
28	26.0980938	50.5721909	0.13	72	26.102727	50.56959	0.12
29	26.096447	50.5726439	0.16	73	26.101788	50.569418	0.11
30	26.0953059	50.573597	0.19	74	26.099877	50.569222	0.16
31	26.089864	50.5734322	0.17	75	26.098853	50.569603	0.13
32	26.1000388	50.5720375	0.23	76	26.0984155	50.5701362	0.14
33	26.0926835	50.573943	0.22	77	26.09944	50.570178	0.20
34	26.093898	50.573978	0.12	78	26.10073	50.569753	0.10
35	26.1034	50.571582	0.12	79	26.104455	50.568967	0.14

Continued, Table (10)

Radiation dose rates and their GPS coordinates in Riffa Views

No.	Latitude	Longitude	(μSv/h)	No.	Latitude	Longitude	(μSv/h)
36	26.104732	50.57112	0.10	80	26.1043396	50.5672365	0.13
37	26.0917385	50.5686121	0.10	81	26.101328	50.554918	0.11
38	26.093708	50.570707	0.20	82	26.101863	50.556815	0.15
39	26.0967633	50.5682964	0.13	83	26.102243	50.559245	0.17
40	26.094172	50.570402	0.12	84	26.1008524	50.5638688	0.13
41	26.0923829	50.5697972	0.12	85	26.102595	50.561505	0.17
42	26.09121	50.567097	0.17	86	26.103085	50.563985	0.18
43	26.0902698	50.5675155	0.15	87	26.10368	50.565668	0.23
44	26.0974547	50.5608985	0.14	88	26.105223	50.568868	0.19

Mapping of the acquired data from Riffa Views indicates that the highest measurement occurred on the 96 Highway as shown in Figure 20. The highest measured radiation dose rate on this Highway is 0.30 μ Sv/h. Many oil wellheads and oil pipelines installations spotted on the sides of the 96 Highway as it is illustrated in Figures 21 and 22. Generally, Riffa Views residential area is characterized by the presence of several oil wellheads and pipelines that are scattered around the neighborhoods of Riffa Views (Figure 23).

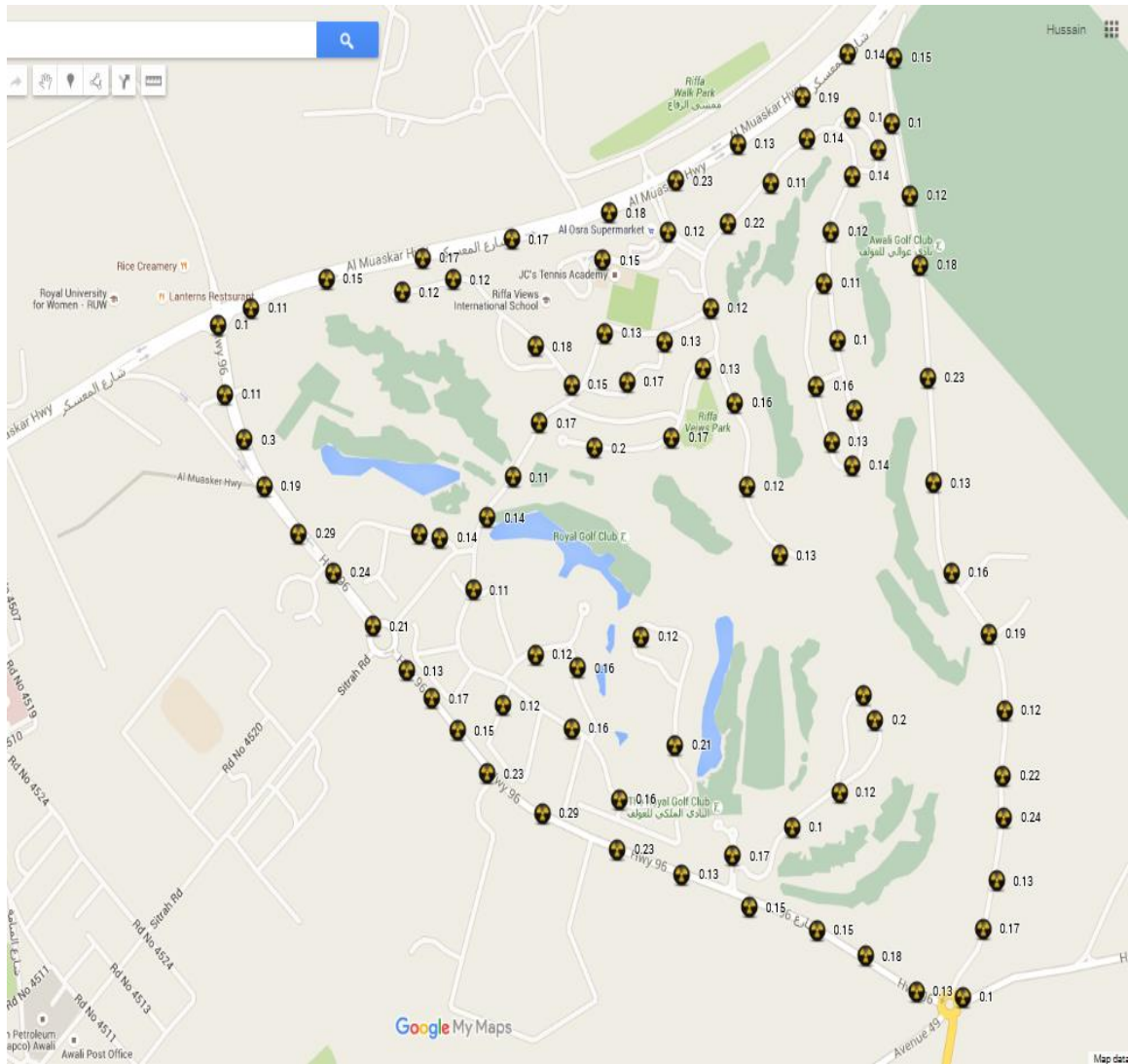


Figure (8)

Mapping of the radiation dose rates in Riffa Views in ($\mu\text{Sv/h}$)



Figure (9)
Oil wellheads on 96 Highway



Figure (10)
Pipelines installations on 96 Highway



Figure (11)

Oil wellheads scattered inside Riffa Views

To obtain an easy comparison of the annual equivalent external radiation doses in both experimental and Isa Town and Al-Budaiya, Figure 24 was generated. It seems that the lowest annual equivalent radiation dose is 0.09 mSv/y acquired in Isa Town while the highest is 4.12 mSv/y occurred in Awali. Concerning the mean annual equivalent doses, the lowest is 0.70 ± 0.24 mSv/y occurred in Al-Budaiya Village. Isa Town demonstrates almost a comparable mean annual equivalent dose to Al-Budaiya, which is 0.79 ± 0.35 mSv/y. The mean annual equivalent dose found in Riffa Views is 1.37 ± 0.44 mSv/y, about twice the dose compared to Isa Town and Al-Budaiya. Not surprisingly, Awali demonstrates the highest mean annual equivalent dose of 2.07 ± 0.66 mSv/y, about three times higher than Isa Town and Al-Budaiya and about twice the exposure found in Riffa Views.

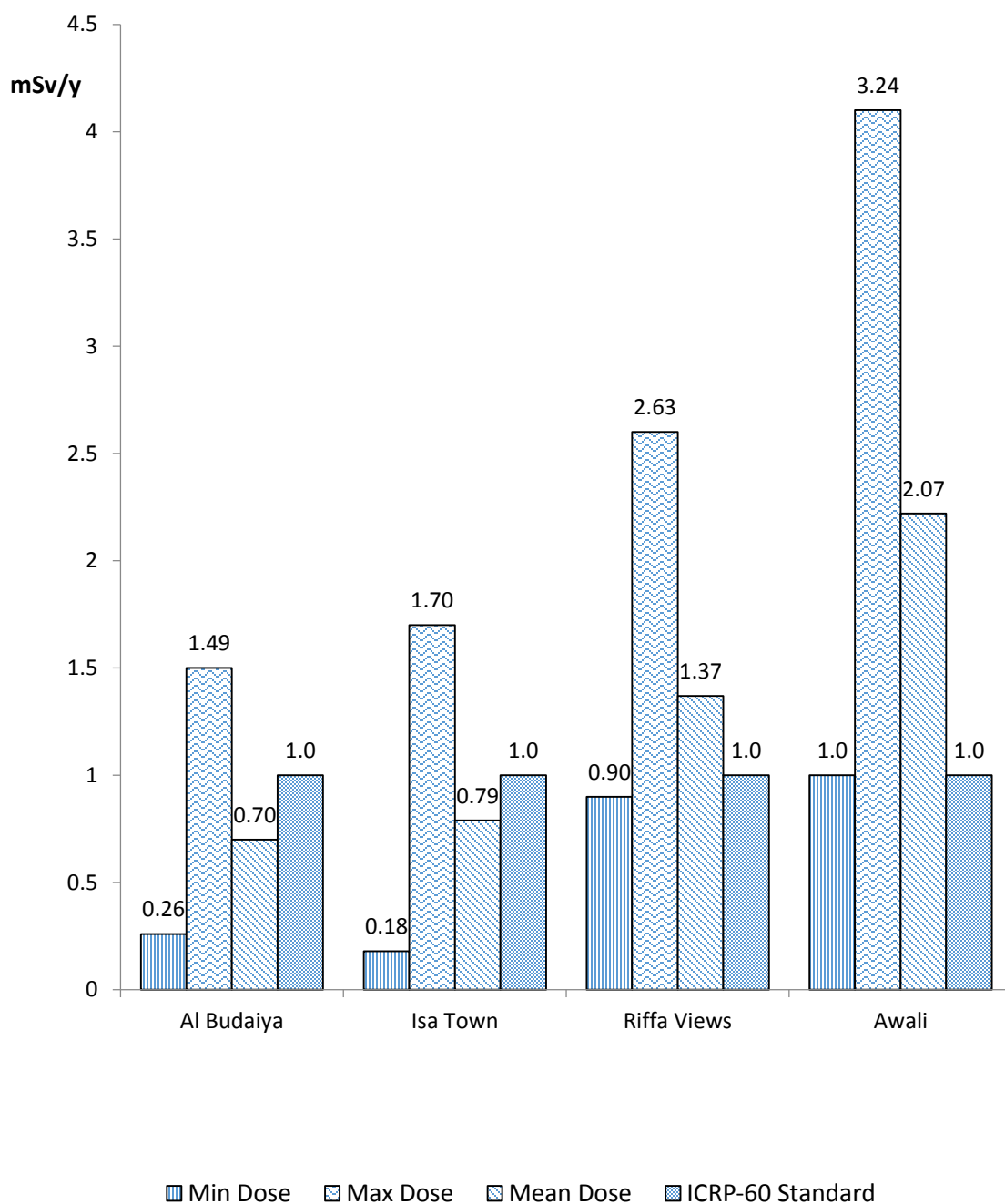


Figure (12)

Min, Max and mean annual equivalent doses (mSv/y) of the four studied areas compared to the ICRP-60 standard radiation dose limit for general public and non-nuclear industrial occupations

4.2 Discussion

This study has been performed to measure the natural external background ionizing radiation in areas in which the radiation profile is expected to be altered due to oil and gas industrial activities in the Kingdom of Bahrain. The oil and gas activities enhance the Naturally Occurring Radioactive Material (NORM) leading to higher radiation levels (Vandenhove, 2000; UNSCEAR, 2008). Awali and Riffa Views residential areas characterize by presence of intense oil and gas operations. Therefore, these areas were selected intentionally as experimental areas.

It is also important to compare the findings obtained from the experimental areas to areas that lack any industrial operations to could alter NORM. Isa Town and Al-Budaiya Village were therefore intentionally selected for this purpose.

The results of this study for the experimental areas and Isa Town and Al-Budaiya Village are summarized in Table 11. This table shows the minimum, maximum and mean equivalent doses for the four studied areas. Table 11 also demonstrates the mean annual equivalent dose for the general public and non-nuclear occupations set according to the ICRP-60 standard.

The results show that the radiation status of the four areas is more profound in the experimental areas than it is in the Isa Town and Al-Budaiya. Although there are some measurements of the radiation equivalent doses that exceed the 1.0 mSv/y as recommended by the ICRP-60 for general public in Isa Town and Al-Budaiya Village, their mean annual equivalent doses lie within the acceptable limits of the ICRP-60 standards. The mean annual

equivalent doses of Al-Budaiya and Isa Town are 0.70 ± 0.24 mSv/y and 0.79 ± 0.35 mSv/y respectively (Table 11) (ICRP-60, 1991).

Similarly, other authors reported similar results to those found in this study. Chad-Umoren and Briggs-Kamara (2010) measured the natural external background radiation in the Rivers State of the Niger Delta region, Nigeria. The mean annual equivalent dose acquired in their unaffected areas by the oil and gas activities was 0.69 ± 0.17 mSv/y. In addition, Agbalagba et al (2013) assessed the natural external background radiation in Delta State in Nigeria. Yet, Agbalagba et al (2013) reported lower radiation levels in their unaffected areas by the oil and gas activities compared to this study in which the mean annual equivalent dose obtained was 0.479 ± 0.11 mSv/y. it seems that lack of industrial activities that alter NORM in the Isa Town and Al-Budaiya could justify the consistency of the low natural external background ionizing radiation measurements in these areas. The mean annual equivalent dose found in all previously described studies fall within the acceptable limits of the ICRP-60.

Table (5)

The results of this study compared to the ICRP standards

Area	Min	Max	Mean $\pm$ SD	ICRP Std. for general public-non nuclear industries
Al Budaiya	0.26 mSv/y	1.49 mSv/y	0.70 ± 0.26 mSv/y	1.0 mSv/y
Isa Town	0.18 mSv/y	1.70 mSv/y	0.79 ± 0.35 mSv/y	1.0 mSv/y
Awali	1.0 mSv/y	3.24 mSv/y	2.07 ± 0.66 mSv/y	1.0 mSv/y
Riffa Views	0.90 mSv/y	2.63 mSv/y	1.37 ± 0.44 mSv/y	1.0 mSv/y

In contrast, the experimental areas of this study show much higher values of annual natural external background radiation. The overall mean annual equivalent dose in Riffa Views and Awali are 1.37 ± 0.40 mSv/y and 2.07 ± 0.66 mSv/y respectively. These values exceeded the ICRP-60

recommendation for up to two folds (Table 11) (ICRP-60, 1991). High radiation values in Riffa Views and Awali are consistent with those found in the literature. Chad-Umoren and Briggs-Kamara (2010) found the mean annual equivalent dose of the oil and gas industrial establishment 1.33 ± 0.08 mSv/y. Similarly, Agbalagba et al (2013) found the mean annual equivalent dose of the oil and gas fields 1.13 ± 0.44 mSv/y. Yet, Hamilton et al (2004) studied the annual external dose from dispersed material in oil and gas fields. They found that the mean annual equivalent dose was 2.8 mSv/y for the operators and 4.1 mSv/y for the assistants.

However, not all residents of Awali are exposed to the same mean annual equivalent dose. It seems that the residents of south and southeastern parts of Awali are exposed to a higher natural external background radiation than the others. The mean annual equivalent dose in some areas of the southern Awali reached up to 3.24 mSv/y with an average of 2.80 ± 0.79 mSv/y. Presence of oil wellheads, pipeline and other oil equipment in the south and southeastern Awali could be one reason for the high radiation measurements. According to Smith (1992), the highest concentration of NORM especially, Radium, is found in the scale and sludge deposits. Scale and sludge deposits are normally found in the linings of the oil pipelines, filters, brine disposal/injection wells and other water handling equipment (Smith, 1992). Gamma ray emissions that result from the decay of the radioactive Radium able to penetrate these equipment (Yehuwdah, 2012). Consequently, the ionization produced by the gamma rays can be detected (Yehuwdah, 2012). Unfortunately, oil wellheads and other oil and gas installations are located just near to the residents' accommodation, as it can be seen from Figures 17, 18 and 19. Therefore, the situation in Awali requires immediate attention as the remedial action is

required if the exposure to the ionizing radiation exceeded 5 mSv/y (ICRP-60, 1991). On the other hand, lack of oil and gas installations in other areas of Awali made the radiation profile much lower in which the calculated mean annual equivalent dose for the rest of Awali is 1.3 ± 0.18 mSv/y.

In Riffa Views, 96 Highway that separates Awali from Riffa Views demonstrates the highest mean annual equivalent dose that reach up to 2.63 mSv/y. Generally, elevated radiation levels in Riffa Views could be regarded to the presence of the oil wellheads and oil pipelines that scattered around the neighborhoods of Riffa Views as illustrated in Figures 21 and 23. According to the EPA (1991), the wellhead piping and production piping near wellheads exhibit high concentration of Radium hence increase NORM.

4.3 Conclusion and Recommendation

Exposure to the natural background ionizing radiation is one of the features on Earth (World Nuclear Association, 2012; CNSC, 2013). Although there are several sources that contribute to the natural external background radiation, one of the main sources is the anthropogenic source (UNSCEAR, 2009). Oil and gas industrial activities increase the Naturally Occurring Radioactive Material (NORM) due to the extraction of deep soil that contains many radionuclides such as Radium (Vandenhove, 2000; UNSCEAR, 2008). As it decays, Radium emits alpha and gamma rays (UNSCEAR, 2009). While a sheet of paper can stop alpha particles, gamma rays able to penetrate the piping and other instruments used to transport and process oil and gas (Yehuwdah, 2012). The interaction of ionizing radiation with the livings increases the probabilities of cancer incidents (Pearce et al., 2012). This study is the first ever attempt to study the level of natural external background

ionizing radiation in the Kingdom of Bahrain. In this framework, Awali and Riffa Views were chosen as experimental areas whereas Isa Town and Al-Budaiya Village were chosen as neutral areas. It is noticeable that Awali and Riffa Views were impacted radiologically as a result of oil and gas activities. The consequent biological damage experienced due to exposure to ionizing radiation is determined mainly by the received radiation dose, duration of exposure, nature of radiation and the sensitivity of the part of the body irradiated (ICRP, 1977; UNSCEAR, 1993).

The management of the ionizing radiation in urban areas is important for environmental health and safety (ICRP, 1977). Strictly speaking in some areas of Awali in which the mean annual equivalent dose for the general public exceeds the permissible dose recommended by the ICRP-60 by three times (ICRP-60, 1991). Therefore, it is important to perform radiological impact assessments to delineate the locations of high ionizing radiation risks (Yehuwdah, 2012; EPA, 2015). The reason for that is to have better control on radiation pollution if the location of risk is known (Yehuwdah, 2012). Many countries have established regulations and guidelines to protect both workers and the general public from NORM generated by oil and gas facilities (Zaidan, 2010). For example, the United Kingdom regulatory control body is the Ionizing Radiation Regulation, 1999 or so called UKIRR 1999 (Radiation Health & Safety Advisory Council, 2005). In Canada, guidelines that are developed to control and manage NORM called CanNORM 2000 (CNSC, 2014). So far the best practices for the individuals and facilities encountering NORM include (IAEA, 2003; CNSC, 2014).

- Any staff working in environment that has possibility of encountering NORM should be provided with training and procedures to deal with it.

- Use of radiation survey meters to evaluate and decontaminate areas of potential NORM contamination.
- Use of personal radiation monitoring devices
- Use personal protective equipment, such as non-porous coveralls, boots and gloves, and protective eyewear and respirators when dealing with NORM-contaminated equipment.
- Follow ALARA 'As Low As Reasonably Achievable' principle: minimize time spent in NORM-contaminated work areas, maximizing the distance from NORM source and use of shielding to minimize dose rates.
- Where there is possibility of presence of NORM, eating, drinking or smoking are prohibited.
- Use ground covers when pipes are scaled to prevent environmental contamination.
- Minimizing operations that may generate dust containing NORM (e.g., cutting, grinding or polishing).
- Storing NORM-contaminated materials (including clothing) in designated areas with access limited to authorized personnel.
- The decontaminated equipment and facilities must be restricted from the public use unless the radiation levels fall within the safe limits. The authorization process should be through a relevant regulatory body.
- Safe disposal of NORM-contaminated materials and avoid stockpiling the material.
- All workers are checked for any contamination with NORM before leaving the work area.

4.4 Suggestion for Further Research

The outcome of this research can be used in several investigations for example:

- Performing a research that study the number and pattern of cancer incidents in areas of high radiation measurements.
- Establishment of a regulations and guidelines to control and monitor industrial activities that could have an impact on NORM.
- Performing a radiological impact assessment for all industrial activities that could be source of NORM.
- Perform a study to characterize the radiation sources in areas impacted by radiation.

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APPENDIX 1



Features

- TTC: $H^*(10)$ dose rate equivalent measurement from background up to 10 Sv/h (1000 rem/h)
- VLD (Patent pending): $H^*(10)$ dose rate equivalent measurement from 10 nSv/h to 1 mSv/h (1 μ rem/h to 100 mrem/h)
- Multiple CSP™ probe host controller
- Mapping applications with GPS, Barcode or RFID reader
- Multiple usability levels via profile and user management
- Easy data transfer and instrument setup with standard PC web browser
- Background subtraction mode
- Timer/Scaler for better MDA
- Large data storage
- Traceability: When, How, Who, Where for each record
- Wired or wireless probe connection
- Large control buttons to accommodate use with gloves
- Large color touch screen
- Easy to read display in all light conditions
- Waterproof to 1 meter depth
- Rechargeable batteries with no memory effect
- Always visible dose-rate display for better user safety
- Standard Bluetooth® headset connection
- Loud audio alarm and vibrator
- Free and easy to upgrade software via PC connection

*ALARA = As Low As Reasonably Achievable



Colibri®: Hand-Held Health Physics Communication ALARA* Platform

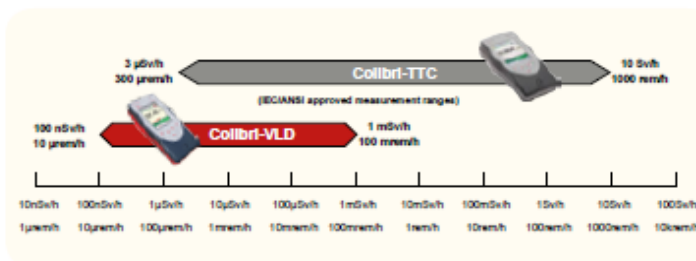
Description

Colibri is a comprehensive health physics instrument with unique characteristics that can lower the dose exposure of HP technicians and other workers in radiation areas. The "always on" gamma dose feature ensures the worker is always informed – even when using the Colibri for contamination surveys with attached probes. The Colibri also allows for wireless data collection from pre-positioned detectors that can be placed in radiation areas – eliminating the need to attach probes, get close to the source – then manually transcribe data. Walk into the room – and Colibri performs the survey for you – allowing exit from the rad area in a fraction of the normal time.

Colibri is available in two different versions:

1. **TTC (grey gasket)** – for radiation area measurements up to 10 Sv/h (1000 rem/h). Colibri TTC will not saturate in case of a sudden increase of radiation and will always provide the user with a reliable and precise dose-rate information when most other conventional instruments will stop measuring. Thus, Colibri TTC is the ideal tool for daily survey inside nuclear buildings, for radiation post accident follow-up and emergency response follow-up (dose and contamination).
2. **VLD – Very Low Dose (red gasket)** for public area measurements starting from 10 nSv/h (1 μ rem/h). Colibri VLD is the smallest versatile instrument capable of measuring precisely and quickly background level of dose-rate changes starting from 10 nSv/h with a saturation limit that allows quantification of significant dose-rate hazard.

The large color touch screen reports real-time, error-free measurements for up to eight CSP-CANBERRA Smart Probes (seven via Bluetooth and one via CSP standard cable) while always displaying dose-rate at worker location.



Colibri: Hand-Held Health Physics Communication ALARA Platform

Colibri provides both fast reacting semi-log bargraph and averaged digital reading for each measurement window. The main window displays either the internal detector dose-rate or the external probe read-out and the secondary window shows the cumulated dose or the Colibri dose-rate when one or multiple external probes are connected.



Figure 1: Colibri screen with external alpha/beta probe connected

It is always ready to go with no-memory-effect rechargeable batteries and accompanies the worker in the field with minimum constraint. It can be worn on the belt with a permanent smooth clip, or held comfortably in the hand using the finger strap and secure wrist strap.

The Colibri's speaker emits alarm sounds as well as other audible signals. In the event of a radiation hazard, regardless of working conditions, an alarm will sound along with a flashing LED and vibrator. The standard available off the shelf Bluetooth headset will better support source and contamination location in noisy environments.

Colibri TTC integrates a GM detector with CANBERRA superior Time-To-Count technique that covers never achieved dose rate range from background up to 10 Sv/h reducing the risk of saturation in unexpected high dose rate situations. Colibri VLD is based on a CsI scintillator with a novel energy compensation technique that improves sensitivity over entire energy range (patent pending). Colibri VLD allows quick measurement of very low dose-rate while other instruments only estimate such background level. Dose-rate is automatically stored every five seconds in a date stamped internal file allowing for post analysis.

Quality assurance and traceability is naturally embedded in Colibri operations for each logged data and answer typical questions like:

Q: When was the measurement taken?	A: With date and time stamped records.
Q: Who drove the measurement?	A: User login settable access.
Q: Was the Instrument/probe calibration valid?	A: Calibration validity check and storage.
Q: Where was the user?	A: Internal GPS and/or external wireless barcode/RFID reader.

Colibri Upgrades

You can download free of charge Colibri upgrades on the firmware upgrade database available at www.canberra.com. This database will provide all further software versions and applications to enable additional features.

Colibri is compatible with all CANBERRA Smart Probes (CSP). The probes extend the capabilities of the instrument to a range of general surveying applications. With CSP design, key components of hardware circuitry (high voltage, amplifier, discriminator, etc.) are located directly inside of the probe housing rather than in the host survey instrument. Also, the intelligence associated with controlling those components is located in the probe – that is, control and storage of key parameters, settings, calibrations, probe ID, alarm settings, etc. Thus the probe is a fully-integrated subsystem acquiring and transmitting the measurement to the instrument, which is used for display.

With high voltage and digitization of the data occurring in the probe rather than the instrument, measurement accuracy is no longer dependent on cable quality as with older analog systems. Also, the probes can be plugged in "hot" without powering down the instrument – the instrument immediately recognizes the probe and automatically switches measurement to the mode required for that specific probe.

Calibrations and QA measurements can be performed directly with the probe, without even using the instrument, by connecting the probe to a computer with the CANBERRA calibration software (CSPS™). This allows Colibris to remain deployed in the field while various probes are being calibrated.

The Colibri can be connected to external probes by a cable. It can also connect to the CSP probes with wireless technology (Bluetooth) via CSP-COM modules, eliminating the need for a cable. This eases contamination surveys as the user is not dependent on cable length and cable coil-ups.

Timer Scaler

Colibri incorporates a scaler timer mode that allows user to select an integration time from 1 s to 255 s and improves MDA. It displays the number of counts for the selected period of time and the average value in selected unit.



Colibri: Hand-Held Health Physics Communication ALARA Platform

Source Finder Mode

The source finder mode has been designed to monitor and display on an easy-to-understand graphic showing the radiation trend vs. time, in any of the pre-selected units. The graphic updates can be chosen within three different dwell times: Fast = 250 ms, Medium = 500 ms or Slow = 1 s.

This mode is useful in decommissioning applications with contamination probes, when the audio control is not enough and when a more precise control is required.

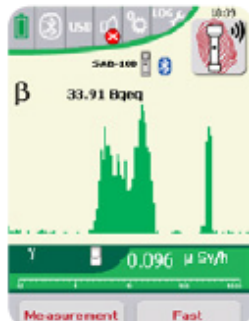


Figure 2: Colibri source finder mode

Background Subtraction

Colibri includes a background subtraction mode. It allows acquisition of a background for a selected duration and subtracts it from next measurements to display and store net results. Colibri allows for the setting of a validity period after which the device will query the user to perform a background update. This mode is useful when performing contamination measurement in a constant background area, thus obtaining measurements reflecting real contamination of a monitored object.

Data-Logging and Mapping applications

Colibri is the perfect instrument for mapping applications. It can save a large number of measurements associated with location data, such as GPS coordinates, barcode, RFID tag or simply an incremental index. GPS is a Colibri internal option while Barcode or RFID readers connect via Bluetooth link.

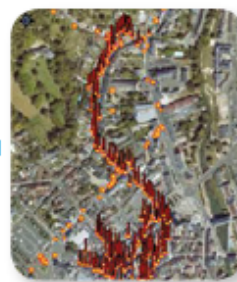
Each logged data is encapsulated with QA information about external probes and/or internal detector calibration traceability. A comment can be entered via a virtual touchscreen keyboard to highlight any specific information for each measurement point.

The automatic data-logging function stores up to 60 000 records of 1 to 255 seconds acquisition with time interval of 0 to 200 000 seconds. It is a powerful mapping tool when GPS coordinates are available.

Colibri manages three date stamped CSV files (MS-EXCEL compatible) for each day of operation:

1. Automatic and transparent storage of dose-rate every five seconds.
2. Manually triggered data-logging with internal detector and/or external probes.
3. Automatic data-logging.

This selection facilitates data retrieval because the user only needs to identify the day of interest.



Example of Automatic Data logging measurements achieved with Colibri GPS and displayed on a map

Colibri Improves ALARA

Colibri will always warn you of any radiation hazard. When used without an external probe, Colibri displays both the dose rate and the cumulative dose taken

since the Colibri has been powered on. When an external probe is connected, it displays both the external probe measurement and the internal dose rate, allowing the user to be aware of the dose rate level when he is focused on the contamination survey.



Figure 3: Colibri with external single channel probe

Colibri features a loud audible alarm, visible LED and vibrator, triggered by alarm set-point for dose-rate, cumulative dose and external probes.

Colibri can connect to remote probes with the wireless Bluetooth link. Probes can transmit measurement data from the hot zone to the user, eliminating the need for the user to enter the hot zone to control the area. It can also be used to assess the radiation risk before entering into a hazardous area. This decreases the total dose exposure for the worker.

Colibri: Hand-Held Health Physics Communication ALARA Platform

A Customizable Instrument

Colibri connects to a PC using a standard web browser for data transfer and instrument setup. Connection can be wired with the USB Colibri cable (part of standard delivery) or wireless with internal Bluetooth link if the user computer is Bluetooth capable.

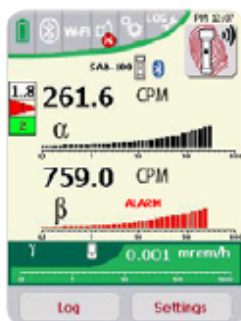
Colibri can be set to any level between fully open and highly restricted for a dedicated worker or a group of users.

Colibri includes user and profile management to adapt the instrument to worker capabilities depending on his primary task. The log-in function can be enabled to bring an additional level of traceability since each measurement stored is then linked to a specific user name or group of users.

Colibri data and parameters are password protected.



Multiple Probe Connection



Colibri can connect to eight CSP probes (one via standard cable and seven via CSP-COM Bluetooth) and display all probe measurements simultaneously. The user can decide to focus on one specific probe manually or automatically if a probe turns an alarm off. The latest alarming probe is always displayed in main window.

Colibri with two probes connected; focus on alpha/beta probe with beta channel alarming

A Ruggedized Platform

Colibri has been built to resist harsh environment constraints. Its ABS housing is shock absorbant. Its silicon rubber keypad provides excellent tactile control compression recovery, and superior resistance to extreme temperatures unlike an ordinary keypad.

Colibri is also waterproof, which makes it operational in extreme environments.

Field Upgradable Software

Colibri software can be periodically upgraded via PC USB link with the standard delivered cable. As a result, user continues to receive the benefit of future software enhancement long after the instrument is purchased.

Colibri comes with a wrist strap, and a rubber finger strap. It also includes a smooth permanent metallic belt clip.

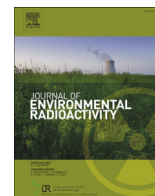


Figure 4: Wrist, belt and hand straps (left); Belt clip in use (right)



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Radiological impact of NORM generated by oil and gas industries in the kingdom of Bahrain

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ABSTRACT

A study of the external background radiation in areas affected by NORM generated by oil and gas industrial activities has been performed in the Kingdom of Bahrain. In this framework, two experimental residential areas, Awali and Riffa Views, were selected due to the presence of extensive oil and gas exploration and transportation. Additionally, two control residential areas, Isa Town and Al-Budaiya Village, were selected as they lack any industrial activities that would disrupt the radiation profile. The radiation dose rates were measured using Colibri Very Low Dose radiation survey meter with a built-in GPS. A total of 317 dose rates with their GPS coordinates were acquired. The lowest dose rate was 0.02 $\mu\text{Sv/h}$ acquired in Isa Town while the highest dose rate was 0.37 $\mu\text{Sv/h}$ acquired in Awali. Since there were no studies performed in the Kingdom to measure the average background radiation, the average external background radiation calculated from the control areas was used in this study which is $0.75 \pm 0.31 \text{ mSv/y}$. The measured mean annual equivalent doses above the background radiation levels in Isa Town, Al-Budaiya, Riffa Views and Awali were $-0.05 \pm 0.05 \text{ mSv/y}$, $0.04 \pm 0.04 \text{ mSv/y}$, $0.62 \pm 0.13 \text{ mSv/y}$ and $1.32 \pm 0.35 \text{ mSv/y}$ respectively. In other words, the radiation measurements were notably higher in the experimental areas. This was particularly true in south and southwestern Awali where the annual equivalent dose in some areas reached 2.49 mSv/y above average background levels. The geological constituent of the earth crust could be one source that contribute to overall background radiation. However, presence of NORM generated by extensive oil and gas operations and transportation is stronger justification for the higher radiation readings in the experimental areas than geological characteristic factor. Such high radiation values were found only near oil and gas installations and not in other locations of the same areas.

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1. Introduction

Background ionizing radiation exists around us from several natural sources. One of these sources is anthropogenic industrial activities which are related to the use of nuclear materials such as nuclear plants and nuclear accidents (Hendry et al., 2009 and Al-Azmi, 2014). Yet, there are other non-nuclear industrial activities that result in enhancement of Naturally Occurring Radioactive Materials (NORM). This often occurs when the radioactive elements from deep underground are brought to the Earth's surface. The oil and gas industry is an example of such industries where NORM are

found in their products and by-products. One of the most common radioactive elements found in oil and gas NORM is radium. Radium is typically associated with oil scale and sludge formations. These formations are usually found in oil pipelines, oil wellheads, disposal and injection wells (UNSCEAR, 2009).

Gamma radiation emitted from radium isotopes are able to penetrate the pipelines and other oil and gas installations causing an external dose of ionizing radiation to the general public and field workers (Yehuwdah, 2012). Exposure to ionizing radiation above certain limits has been proven to increase the incidence of cancer and leukemia among humans (Pearce et al., 2012). For that reason, it is important to monitor radiation pollution sources to ensure that the quality of the environment is maintained in a good state to achieve high level of social performance.

According to the ICRP-60 standards, general public and non-nuclear industrial occupations should not be exposed to radiation

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Table 1

The total number of the radiation measurements, the minimum, the maximum and the mean dose rates obtained in Isa Town, Al-Budaiya Village, Riffa Views and Awali.

Location	No. of measurements	Dose ($\mu\text{Sv/h}$)	
		Range	Mean $\pm$ SD
Isa Town	122	0.02–0.19	0.09 $\pm$ 0.04
Al Budaiya	47	0.03–0.17	0.08 $\pm$ 0.03
Riffa Views	88	0.10–0.30	0.16 $\pm$ 0.05
Awali	60	0.11–0.37	0.24 $\pm$ 0.08

Table 2

The results of the unpaired *t*-test of the experimental areas compared to the control areas.

Study areas	<i>t</i> - value	<i>p</i> - value
Awali compared to Isa town	14.84559	<0.00001
Awali compared to Al-Budaiya	12.58055	<0.00001
Riffa compared to Isa Town	6.07616	<0.00001
Riffa compared to Al-Budaiya	8.76943	<0.00001

from external sources greater than 1 mSv/y above natural background radiation levels (ICRP-60, 1991). The aim of this standard is to reduce ionizing radiation stochastic effects to an acceptable level and to prevent their deterministic effects.

Many studies reported presence of high ionizing radiation levels in oil and gas fields including their host communities. For instance, Hamilton et al. (2004), and Chad-Umoren and Briggs-Kamara (2010), found that oil and gas industrial areas exhibit higher mean annual equivalent doses compared to control areas.

The main objective of this study is to measure the external background radiation in areas affected by NORM generated by oil and gas industrial activities in the Kingdom of Bahrain.

2. Materials and methods

2.1. Study areas

Residential areas, Awali and Riffa Views were selected as experimental areas. These areas are characterized by the presence of extensive oil and gas exploration and transportation; maze of oil pipelines, well-heads, sumps and numerous other oil-field installations.

Isa Town and Al-Budaiya Village were selected as control areas. These areas lack any industrial activity that could interfere with the natural radiation profile.

2.2. Geological features

The rocks and soil of the experimental areas are composed of the Rus Formation, more specifically, the Awali Carbonate Formation. This formation consists of equiangular, fine grained to medium grained, chert-bearing dolomitic limestones with small but variable amounts of quarts and clay minerals (Willis, 1967; Doornkamp et al., 1980).

Whereas the rock and soil of Isa Town are composed mainly of the Dammam Formation, predominantly Al-Buhayr Carbonate Formation. This formation consists of laminated, rusty, yellow-orange argillaceous dolosilite and may also contains clay pockets. The northern west coastal side of the Kingdom of Bahrain in which Al-Budaiya Village is located has been given little scientific

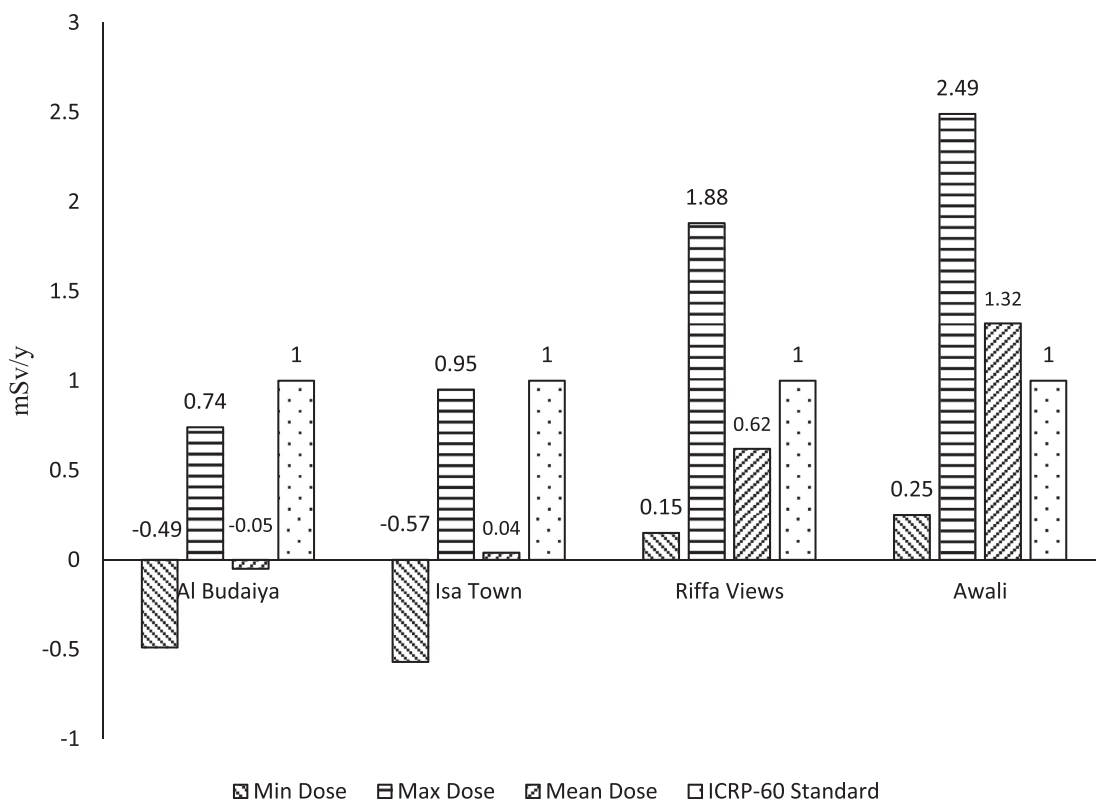


Fig. 1. The minimum, maximum and mean annual equivalent doses (mSv/y) of the four studied areas after subtracting the average background radiation compared to the ICRP-60 standard radiation dose limit for general public and non-nuclear industrial occupations.

description. However, the surface of this area is covered mostly by sand, silts and gypseous quartzose sand (Willis, 1967; Doornkamp et al., 1980).

Radium isotopes are usually associated with carbonate formations for instance, clay-rich formations that contain shale, granites and some sandstones. The oil and gas generally are found in these formations (Smith, 1992).

2.3. Tools

A hand-held radiation survey meter, Colibri Very Low Dose (VLD) with a built-in GPS, was used to measure and map the external background radiation. This survey meter is capable of measuring a very low dose-rate starting from 10 nSv/h to 1 mSv/h.

Colibri VLD is based on a cesium iodide (CsI) scintillator with a novel energy compensation technique that improves sensitivity over the entire energy range. In addition, this meter stores up to 60,000 records of 1–255 s acquisition with time interval of 0–200,000 s (Canberra, 2015).

2.4. Methodology

The survey meter was mounted on a vehicle at height of 1 m above ground level. The meter's GPS was enabled so that every acquisition was documented with its satellite coordinates. The data were measured at 300 m intervals in a drive-stop mode. Each radiation dose rate was acquired for 10 s as recommended by the manufacturer of the meter. The route was chosen to cover the

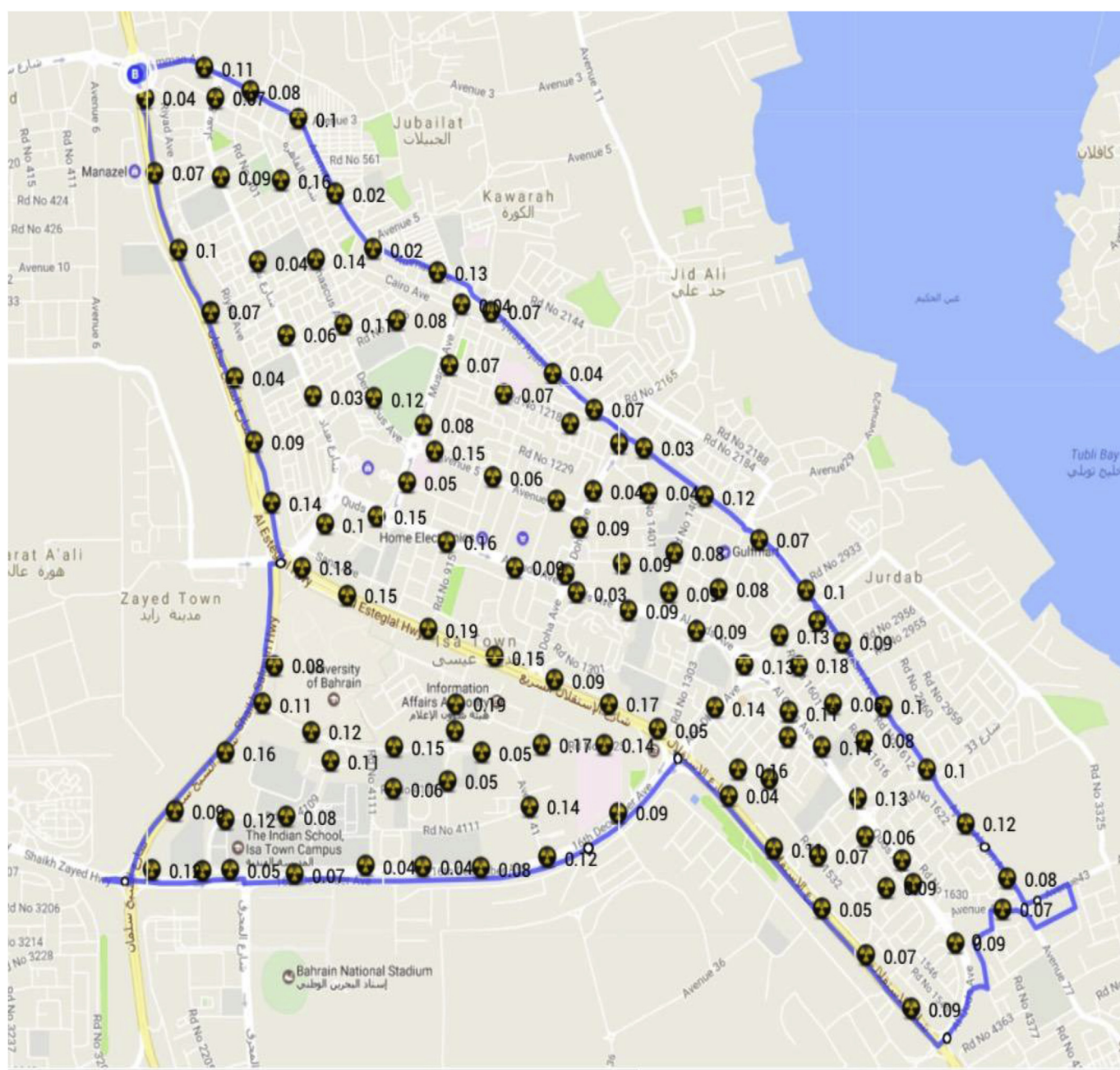


Fig. 2. Mapping of the radiation dose rates in Isa Town in $\mu\text{Sv/h}$. The blue outline demonstrates the perimeter of Isa Town. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

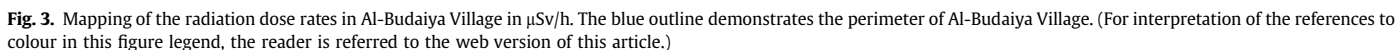
The Standard Deviations (SD) of the dose rates and mean annual equivalent doses were calculated. Maps of the distribution of the radiation data of each studied area were then generated using Google Map Macro online application.

A total of 122 measurements were acquired in Isa Town [Table 1](#). The dose rates in this area ranged from 0.02 $\mu\text{Sv/h}$ to 0.19 $\mu\text{Sv/h}$ with mean dose rate of $0.09 \pm 0.04 \mu\text{Sv/h}$. In Al-Budaiya Village, 47 measurements were acquired ranging from 0.03 $\mu\text{Sv/h}$ to 0.17 $\mu\text{Sv/h}$ with mean dose rate of $0.08 \pm 0.03 \mu\text{Sv/h}$.

The unpaired *t*-test was performed to examine whether the

Since there were no studies performed in the Kingdom to measure the average background radiation, the average external background radiation calculated from the control areas was used as a representative data for the Kingdom of Bahrain in this study. The average background radiation calculated from the control areas is 0.75 ± 0.31 mSv/y.

Fig. 1, demonstrates the annual equivalent radiation doses of the studied areas after subtracting the average annual background radiation. The maximum equivalent radiation dose measured in Al-Budaiya and Isa Town were 0.75 mSv/y and 0.95 mSv/y respectively. These data lie within the permissible limit set by the ICRP-60 which is 1 mSv/y (Fig. 1). These results could be justified by the lack



of industrial activities that would alter NORM in control areas. The spread and mapping of the radiation values of Isa Town and Al-Budaiya Village are given in Fig. 2 and Fig. 3 respectively.

The highest annual equivalent doses in Riffa Views were acquired on the Highway 96. The equivalent radiation dose on this highway range from 0.13 mSv/y to 1.88 mSv/y, with a mean of 1.35 ± 0.83 mSv/y above the average background radiation level, (Fig. 4). Many oil wellheads and oil pipelines installations located along of this Highway could justify such elevated radiation values. Nevertheless, the mean equivalent dose in Riffa Views is 0.62 ± 0.13 mSv/y, within the acceptable limit of the ICRP-60.

In the second experimental area Awali, the mean annual equivalent radiation dose is 1.32 ± 0.35 mSv/y above the background levels, slightly higher than the ICRP-60 limits. However, the highest equivalent radiation dose of 2.49 mSv/y occurred in southern Awali. This value exceed the ICRP-60 standards more than two folds. Interestingly, south and southeastern Awali exhibit

higher radiation values compared to north and northwestern Awali (Fig. 5). The mean annual equivalent dose in south and south-eastern Awali is 2.05 ± 0.48 mSv/y above the average background radiation level. There are several oil wellheads, pipelines and other oil equipment in the south and southeastern Awali that might be an explanation of these high radiation measurements.

High radiation values in the experimental areas were measured in locations near oil and gas facilities while other locations of the same area that lack or are away from oil and gas facilities exhibit normal radiation values. This delineate that the cause of the high equivalent radiation doses are due to the presence of NORM generated by oil and gas activities rather than other factors, in other words, exclude the geological factor.

Unfortunately, oil wellheads and other oil and gas installations are located in close approximation to the residents' accommodation in Riffa Views and Awali, Fig. 6. Therefore, there is a need for attention as remedial action is required if exposure to ionizing

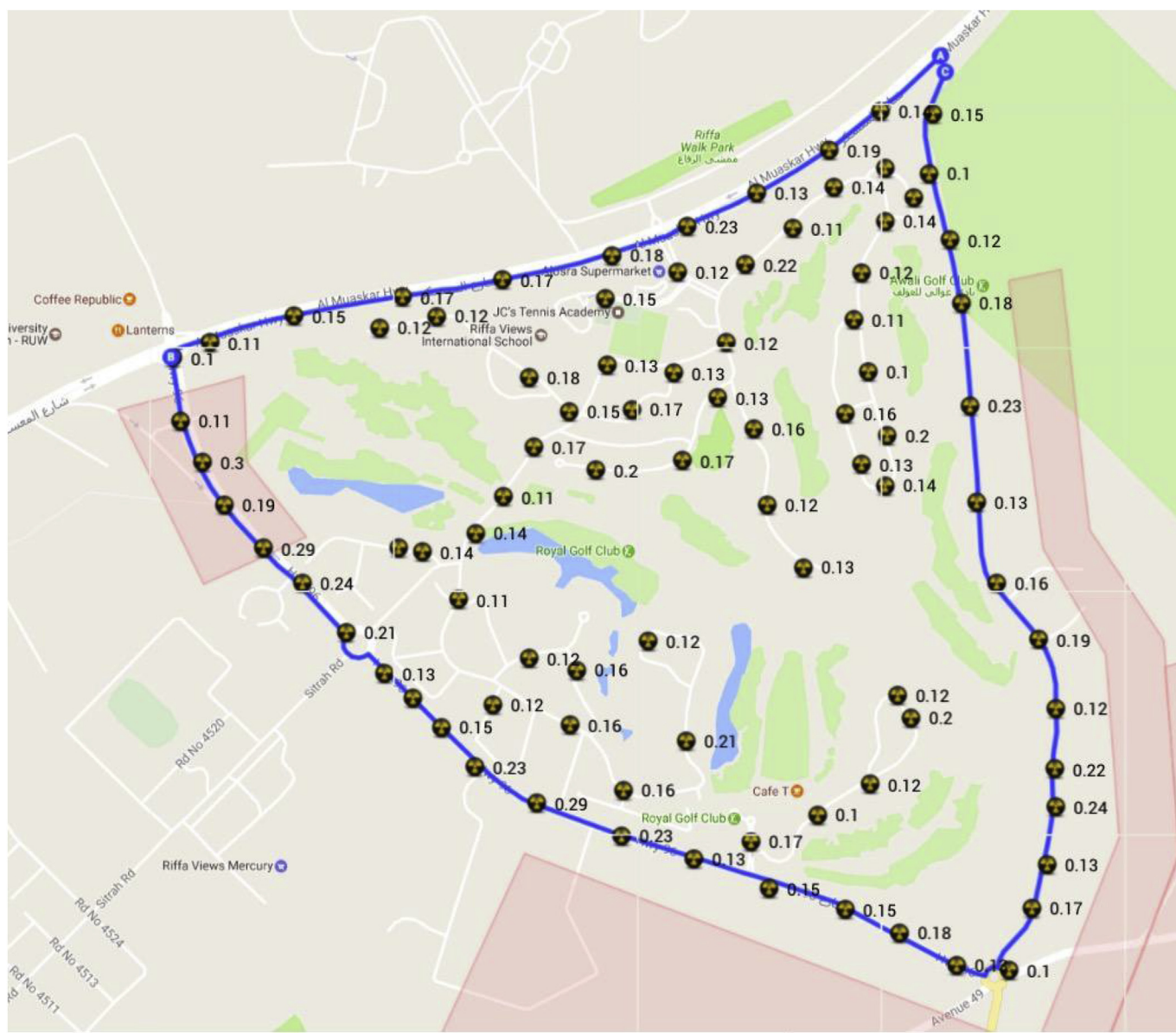


Fig. 4. Mapping of the radiation dose rates in Riffa Views in $\mu\text{Sv/h}$. The blue outline demonstrates the perimeter of Riffa Views. The red zones on the map demonstrate areas of oil and gas installations and pipelines. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

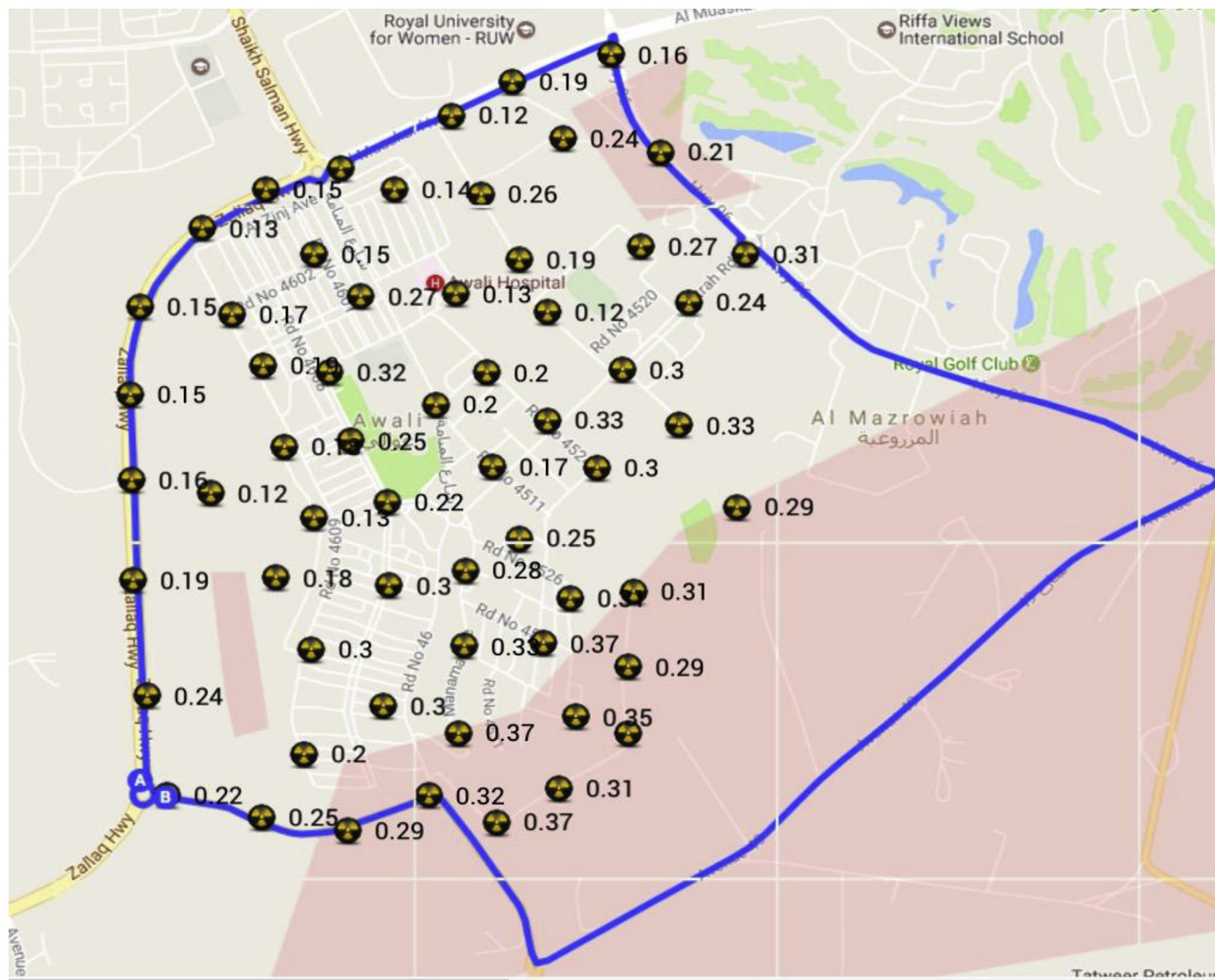


Fig. 5. Mapping of the radiation dose rates in Awali in $\mu\text{Sv/h}$. The blue outline demonstrates the perimeter of Awali. The red zones on the map demonstrate areas of oil and gas installations and pipelines. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

radiation exceeds 5 mSv/y above the average background radiation (ICRP-60, 1991).

4. Conclusion and recommendation

The external background radiation was measured in areas affected by NORM generated by oil and gas industries in the Kingdom of Bahrain. The results of this study showed that Riffa Views and Awali residential communities were impacted radiologically due to extensive operations and transportation of oil and gas. The measured equivalent radiation doses in Riffa Views and Awali are 0.62 mSv/y and 1.32 mSv/y above the average external background radiation respectively. While highest radiation measurements were acquired near some oil and gas installations, well heads and pipelines, other locations of the same area that lack oil and gas installations exhibit normal radiation profile. This indicates that the cause of high radiation measurements is more likely to be as a consequences of NORM generated from oil and gas industry rather than other causes, in other words, geological factor. Such increase in the radiation levels may not pose immediate hazard, but in the long-term, the cumulative radiation dose may be significant.

Long-term exposure to low levels of ionizing radiation has been confirmed to increase the incidents of cancers and leukemias (Pearce et al., 2012). Therefore, it is important to perform radiological impact assessments in the Kingdom of Bahrain to delineate the locations of high ionizing radiation risks. The reason for that is to have better control on radiation pollution if the location of risk is known. Like many other countries, it is the time for the concerned authorities in the Kingdom of Bahrain to issue rules and guidelines to protect the environment, general public and the field workers from NORM generated by certain industrial activities. A good example for guidelines to monitor and control NORM related to the industrial activities are the Ionizing Radiation Regulation, 1999 or so called UKIRR 1999 in the United Kingdom and the CanNORM 2000 in Canada (CNSC, 2014). In addition, the outcome of this research can be used in several investigations for example:

- Performing a research that correlate the number and pattern of cancer incidents in areas of high radiation measurements.
- Performing a radiological impact assessment for all industrial activities that could be source of NORM.



Fig. 6. Oil wellheads found scattered in close approximation of the residents' accommodation in Riffa Views and Awali.

- Perform a study to characterize the radiation sources in areas impacted by radiation.

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الملخص

تم القيام بدراسة الإشعاعات الخارجية الخلفية الطبيعية في مملكة البحرين. إنه من المعروف أن عملية استخراج النفط والغاز تعززان المواد المشعة المحدثّة طبيعياً (نورم) مما يؤدي إلى زيادة معدلات الإشعاع. عوالي والرفاع فيوز منطقتان سكنيتان تقعان في وسط مملكة البحرين، تتميزان بوجود عمليات استخراج ونقل مكثفة للنفط والغاز. لذا تم اختيارهما كمنطقتين تجريبيتين. تمت مقارنة النتائج التي تم الحصول عليها من عوالي والرفاع فيوز بمناطق مراقبة، وتحديدًا: مدينة عيسى والبديع. تتميز هذه المنطقتين بعدم وجود أي نشاطات صناعية بإمكانها تغيير منهجية المواد المشعة. تم استخدام جهاز مسح الإشعاع المنخفض كوليبيري Colibri Very Low Dose المدمج مع نظام تحديد المواقع لقياس ورسم خريطة الإشعاعات الخارجية الخلفية الطبيعية لكلٍ من المناطق التجريبية ومناطق المراقبة. قبل القياس، تم تفعيل نظام تحديد الملاحية المدمج في جهاز المسح الإشعاعي وتم قياس الإشعاعات يدوياً لكل مسافة 300 متر وعلى إرتفاع متر واحد من سطح الأرض. وتم رسم الخرائط الإشعاعية باستخدام تطبيق جوجل ماكرو للخرائط على الإنترنت. تبين النتائج بأن أدنى قياس لمعدل الجرعات الإشعاعية هو 0.02 مايكرو سيفرت / ساعة والذي سجل في مدينة عيسى بينما سجل أعلى معدل إشعاعي في عوالي وكان 0.37 مايكرو سيفرت / ساعة. بالنسبة إلى متوسط الجرعة الإشعاعية المكافئة السنوية لمدينة عيسى فقد كانت 0.26 ± 0.70 ملي سيفرت / سنة، البديع كانت 0.35 ± 0.79 ملي سيفرت / سنة، عوالي كانت 0.66 ± 2.07 ملي سيفرت / سنة والرفاع فيوز كانت 0.44 ± 1.37 ملي سيفرت / سنة. من النتائج يتبين بأن المناطق التجريبية تعدت الحد الأقصى المسموح به وهو 1.0 مللي سيفرت / سنة والموصى به من قبل ICRP-60. خصوصاً في شرق وجنوب عوالي حيث أن متوسط الجرعة الإشعاعية المكافئة السنوية شارفت 0.79 ± 2.80 ملي سيفرت / سنة. ارتفاع معدلات الإشعاع في عوالي والرفاع فيوز من الممكن إرجاعها إلى وجود عمليات مكثفة للنفط والغاز الطبيعي في تلك المناطق.

جامعة البحرين

قسم الفيزياء

كلية العلوم



قياس الأشعة الخلفية الخارجية الطبيعية في المناطق المتأثرة بالنورم في مملكة البحرين

أطروحة مقدمة كجزء من متطلبات الحصول على درجة الماجستير في البيئة والتنمية المستدامة

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